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Using computational physics methods to improve high school students' understanding of dynamics concepts

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Abstract: With the continuous development of physics education, how to help high school students better understand the complex concepts of dynamics has become an important challenge in teaching. Traditional teaching methods have certain limitations in explaining abstract concepts such as the laws of motion and the relationship between velocity and acceleration, while computational physics methods can intuitively show the motion process and dynamic changes through numerical simulation and visualization techniques to help students understand the core principles of dynamics more deeply. This paper proposes an idea of using computational physics methods to assist the teaching of high school dynamics, and demonstrates the practical application and advantages of computational physics in teaching through examples of uniform linear motion, uniformly accelerated motion and parabolic motion. The study shows that this method can not only improve students' mastery of the concept of dynamics, but also cultivate their ability to analyze and solve problems, thus providing an effective and innovative means for high school physics teaching.

1. Introduction

Dynamics is one of the important contents of high school physics, covering core concepts such as velocity, acceleration, force and laws of motion[1]. Due to the high abstraction and complex mathematical derivation process of the theory of dynamics, students often face greater difficulties in the process of understanding, especially when linking the theoretical formulas with the actual motion phenomena, which is prone to understanding bias[2]. The traditional teaching method mainly relies on formula derivation and static experiments, and lacks the dynamic display of the motion process, which makes it easy for students to stay at the surface cognitive level when learning dynamics, and it is difficult for them to deeply understand its physical meaning.

With the rapid development of computer technology, computational physics and numerical simulation techniques are increasingly used in physics teaching[3]. Using computational physics methods, complex motion processes can be visualized in the form of dynamic graphics through numerical computation and visualization, so that students can explore and understand dynamical phenomena in the simulation environment[4]. This approach can not only transform abstract concepts of dynamics into visualized teaching content, but also effectively enhance students' interest and active participation, thus deepening their understanding of the laws of dynamics.

The purpose of this paper is to explore how to introduce computational physics methods into high school physics teaching, using computer simulation and visualization techniques to help students understand the concept of dynamics more intuitively[5]. By designing a series of typical dynamics simulation cases, uniform linear motion, uniformly accelerated motion and parabolic motion, etc., this paper enables students to set the parameters and observe the motion process independently, thus deepening their understanding of the physics concepts[6]. The practical significance, challenges and corresponding solutions of the implementation of computational physics methods in high school physics teaching are discussed to provide a reference for the innovation of physics teaching.

2. The significance of computational physics methods in teaching dynamics

The computational physics method brings a brand-new teaching tool and approach to high school dynamics teaching[7]. Traditional physics teaching methods mainly rely on formula derivation and experimental verification, and students often can only observe physical phenomena from a static perspective, making it difficult for them to fully understand the dynamic process[8]. Through computational physics methods, teachers can use numerical calculations and visualization tools to transform complex dynamical phenomena into intuitive simulation images to help students observe and understand physical phenomena from a dynamic perspective, making abstract physical concepts more vivid and concrete, and helping to overcome the limitations of traditional teaching[9]. Computational physics methods can significantly enhance students' intuitive understanding and motivation to explore. In a simulation environment, students can not only observe the trajectory of an object's motion, but also explore the characteristics of motion under different conditions by changing parameters (e.g., initial velocity, acceleration, and force) [10]. The process of active participation can effectively stimulate students' interest, enable them to think more deeply about the principles behind the concepts of dynamics in dynamic and interactive learning, develop the ability to explore independently, and promote deep learning.

Computational physics methods can also provide students with more challenging problem situations and enhance their analytical and problem-solving skills. In real physical phenomena, many problems cannot be solved by simple analytical methods, while computational physics methods can help students solve these complex problems through numerical simulations and iterative calculations. By simulating the collision of two objects, students can analyze and understand the conservation of energy and momentum in complex mechanical systems. This teaching method can exercise students' critical thinking and ability to synthesize and apply knowledge, laying the foundation for more in-depth physics learning.

The application of computational physics methods is in line with the innovative trend of modern education and can enhance students' computational thinking and information literacy. With the continuous popularization of information technology, mastering basic computer operation and understanding simple programming ideas have become a necessary skill. Through the introduction of computational physics methods, students can gradually come into contact with basic computational methods such as numerical computation and data analysis while learning dynamics, laying a foundation for future learning and development. The computational physics method enhances the teaching effect of dynamics and has far-reaching significance for the cultivation of students' overall scientific literacy and innovation ability.

3. Examples of applications of computational physics methods

Computational physics methods have rich applications in teaching dynamics, through numerical simulation and visualization, students can understand various laws of motion more intuitively. The following simulations of uniformly accelerated linear motion, uniformly accelerated linear motion and parabolic motion are used to demonstrate the specific applications and teaching effects of computational physics methods in different dynamics contexts.

3.1. Numerical simulation of uniform linear motion

Uniform linear motion is one of the most fundamental kinetic concepts in high school physics, which describes the motion of an object along a straight line trajectory at a constant velocity. In traditional teaching, students often use the formula $v = \frac{\Delta x}{\Delta t}$ to understand the relationship between velocity, displacement and time. The mere derivation of formulas lacks intuition for some students, and it is difficult for them to understand the actual state of uniform linear motion and its regularity. In numerical simulation, students can set the initial velocity and motion time of an object through a computer program, observe the displacement of the object at different time points, and generate displacement-time images. This intuitive visualization enables students to clearly see the characteristics of uniform motion, i.e., the law that displacement increases linearly with time. Students can repeatedly change the initial conditions and observe the effect of different speeds on the change of displacement, thus gaining a deeper understanding of the concept of velocity. This interactive learning method can effectively enhance students' interest in learning and depth of understanding.

Through numerical simulation, students can also analyze the constant velocity properties of uniform linear motion. In the simulation program, it can be set to record the displacement of an object every second, and then verify the constancy of velocity by calculating the difference in displacement within each second. This process allows students to experience the central characteristic of uniform linear motion from a computational perspective: constant velocity. This hands-on process gives students a more concrete and solid understanding of the definition of velocity and the laws of uniform linear motion.

Numerical simulations can also help students understand the difference between uniform linear motion and other forms of motion. Through comparative simulation with accelerated motion, students can visualize the linear characteristics of uniform motion trajectories and the nonlinear characteristics of accelerated motion. This comparison can deepen students' understanding of the nature of uniform motion and make them realize the differences in the changes of velocity and displacement under different forms of motion, thus laying the foundation for the subsequent study of more complex dynamics.

3.2. Visualization of uniformly accelerated linear motion

Uniformly accelerated linear motion is a common type of motion in dynamics that characterizes the motion of an object along a straight line trajectory under constant acceleration. In traditional teaching, students use formulas $s = v_0 t + \frac{1}{2} a t^2$ To understand the relationship between displacement, initial velocity, acceleration and time, simple symbols and formulas are more abstract for students, and it is difficult to form an intuitive understanding. Students can also adjust the acceleration value to observe the change of displacement with time under different acceleration, so as to deeply understand the role of acceleration. This graphical presentation can help students more directly recognize the effect of acceleration on motion.

Visualization can also be used to generate velocity-time plots to further explain the changing patterns of velocity. Through the linear upward trend of the velocity-time graph, students can visually observe that the rate of increase of velocity is constant, which is consistent with the characteristics of uniformly accelerated motion. At the same time, the linear slope in the image corresponds to the magnitude of acceleration, allowing students to more clearly understand the relationship between velocity and acceleration. This graphical analysis allows students to verify the definition and characteristics of uniformly accelerated motion in concrete data and images, deepening their understanding of acceleration.

Visual simulations of uniformly accelerated linear motion help students compare uniformly accelerated and non-uniformly accelerated motion in different contexts. By comparing the displacement-time and velocity-time graphs under the two types of motion, students can see how changes in acceleration affect the motion of an object. This visual comparison experiment allows students to more clearly recognize the uniqueness of uniformly accelerated motion and lays a solid foundation of understanding for their further study of non-uniformly accelerated motion and complex laws of motion, as shown in Figure 1.

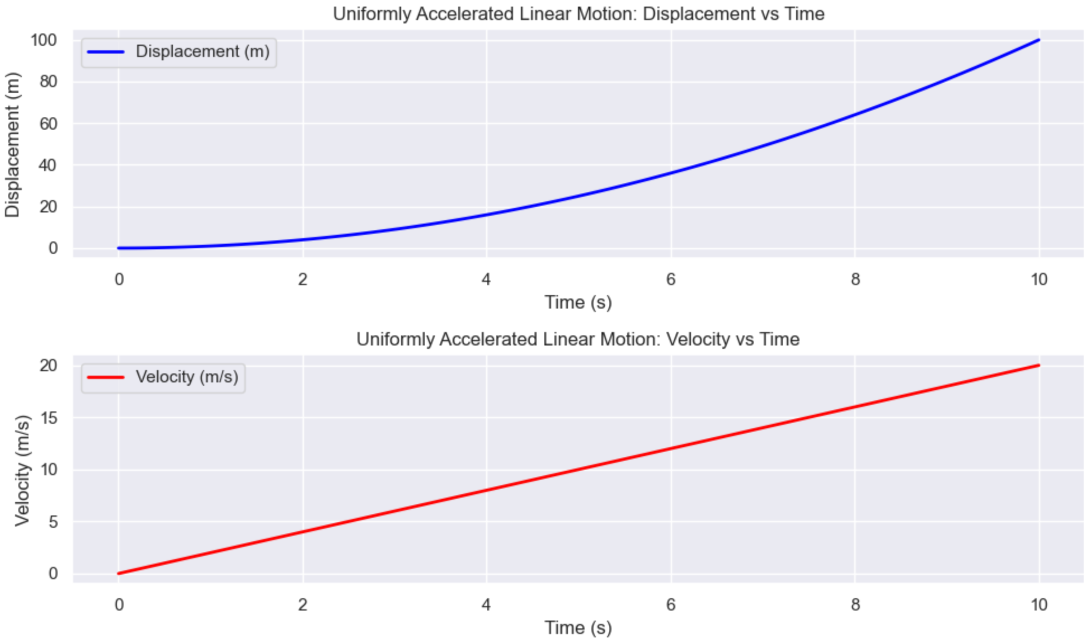

Figure 1: Uniformly Accelerated Linear Motion and Uniformly Accelerated Linear Motion

3.3. Trajectory simulation of parabolic motion

Parabolic motion is one of the more complex dynamical motions in high school physics, involving the phenomenon of an object moving along a parabolic trajectory under the action of initial velocity and gravity. In traditional teaching, the trajectory of parabolic motion is usually explained by formula derivation, and students need to understand the independence of horizontal and vertical motion. The two-dimensional nature of parabolic motion makes it difficult for students to intuitively grasp the characteristics of its motion by formula derivation alone. Through trajectory simulation in computational physics, students can dynamically observe the complete process of parabolic motion and thus more clearly understand the characteristics of this form of motion. In the trajectory simulation, students can set the initial velocity, throw angle and gravitational acceleration of the object, and observe the real-time position change of the object in the horizontal and vertical directions. Through the computer-generated trajectory diagram, students can see the whole process of the object moving along the parabolic path, which visualizes the curvilinear characteristics of parabolic motion. Students can also adjust the angle of projection and initial velocity and observe their effects on the shape of the trajectory and the distance traveled, so as to better understand the importance of the initial conditions in parabolic motion.

Trajectory Simulation generates displacement-time and velocity-time diagrams of an object in the horizontal and vertical directions to help students understand the characteristics of partial motion in two directions in parabolic motion. The horizontal displacement-time diagram shows the uniform motion of the object in the horizontal direction, while the vertical velocity-time diagram shows the velocity trend of the object under the influence of gravitational acceleration. This graphical display helps students clearly distinguish the laws of motion in the horizontal and vertical directions, and gives them a more intuitive understanding of the decomposition nature of parabolic motion. Students can conduct several simulations with different initial conditions and measure data such as the flight time and maximum height of the projectile to compare with theoretical calculations. This hands-on process not only allows students to experimentally verify the accuracy of the physics formulas, but also enhances their understanding of parabolic motion and their awareness of experimental errors. This computational physics simulation not only deepened students' understanding of parabolic motion, but also developed their experimental analysis and critical thinking skills.As shown in Figure 2.

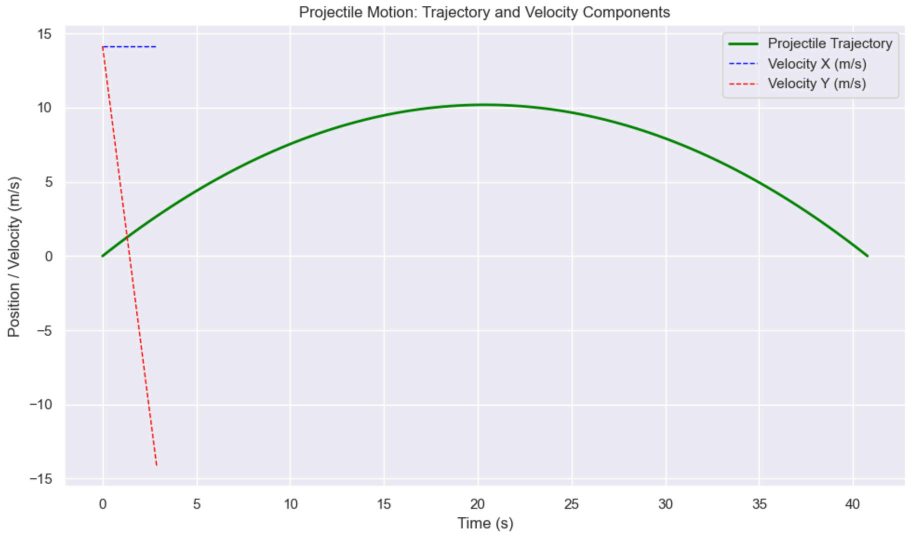

Figure 2: Projectile Motion Trajectory Simulation

4. Implementation and Challenges of Computational Physics Methods in Teaching Dynamics

The implementation of computational physics methods has brought new perspectives and teaching tools to the teaching of dynamics. To effectively integrate computational physics into high school physics teaching requires teachers to have certain computer programming skills and proficiency in numerical simulation tools. In the traditional teaching mode, physics teachers rely more on manual derivation and experiments to help students understand physical concepts, and computer programming and numerical simulation are not regular teaching tools. Teachers need to master the basic theories and applications of computational physics through professional training or independent study in order to effectively utilize these tools in teaching. This shift requires teachers to update their educational concepts and proactively adapt to changes in modern educational technology. The application of computational physics methods requires schools to have appropriate hardware facilities and software support. Numerical simulation and visualization tools usually require certain computational resources, computers, projection equipment and professional simulation software. In some underprivileged schools, especially those in remote areas, the lack of hardware facilities and software may become an obstacle to the implementation of computational physics teaching. Students also need to have some computer skills, especially when conducting simulation experiments, which require the use of programming languages such as Python and Matlab for data input, processing and visualization. This need places high demands on students' computer fundamentals, and schools need to provide students with the relevant training to better adapt to this teaching methodology.

5. Conclusion

Computational physics methods improve the interactive and intuitive nature of teaching and learning, and present certain pedagogical difficulties. Unlike traditional paper-based assignments and experiments, computational physics methods require students to have certain numerical analysis skills and programming thinking when using simulation tools. Some students may be unfamiliar with programming and may have difficulties in understanding and operating the simulation tools. Teachers need to tutor programming skills in addition to explaining physical concepts when implementing computational physics to help students overcome technical difficulties. Teachers not only need to have knowledge of physics, but also need to have some computer teaching skills to be able to effectively guide students through simulation experiments.

The implementation of computational physics methods also faces the challenge of balancing theoretical teaching and numerical simulation. Although numerical simulation can help students understand physical phenomena more intuitively, too much reliance on computer simulation may lead to students ignoring the importance of physical formula derivation and practical experimental verification. To achieve the maximum benefits of teaching computational physics, teachers need to allocate time and effort in the instructional design to take full advantage of numerical simulation and visualization techniques, while maintaining the traditional way of teaching physics theory and experiments. Through this balance, students are able to master dynamics more comprehensively on the basis of hands-on experiments and computer simulations, enhancing their comprehensive analytical ability and innovative thinking.

References

[1] Laizet S, Li N.Incompact3d: A powerful tool to tackle turbulence problems with up to O(105) computational cores[J].International Journal for Numerical Methods in Fluids, 2011, 67(11):1735-1757.DOI:10.1002/fld.2480.

[2] Tornberg A K, Shelley M J.Simulating the dynamics and interactions of flexible fibers in Stokes flows[J].Journal of Computational Physics, 2015, 196(1):8-40.DOI:10.1016/j.jcp.2003.10.017.

[3] Morris P J, Long L N, Bangalore A.A Parallel Three-Dimensional Computational Aeroacoustics Method Using Nonlinear Disturbance Equations[J].Journal of Computational Physics, 1997, 133(1):56-74.DOI:10.1006/jcph. 1997. 5646.

[4] Beckett G, Mackenzie J A, Ramage A, et al.On The Numerical Solution of One-Dimensional PDEs Using Adaptive Methods Based on Equidistribution[J].Journal of Computational Physics, 2001, 167(2):372-392.DOI:10.1006/jcph. 2000. 6679.

[5] Luo Z, Tong L, Ma H.S hape and topology optimization for electrothermomechanical microactuators using level set methods[J].Journal of Computational Physics, 2009, 228(9):3173-3181.DOI:10.1016/j.jcp.2009.01.010.

[6] Huang Z , Lee J , Henkensmeier D ,et al.Effect of Molecular Structure and Coordinating Ions on the Solubility and Electrochemical Behavior of Quinone Derivatives for Aqueous Redox Flow Batteries[J].Journal of The Electrochemical Society, 2020, 167(16):160502 (8pp).DOI:10.1149/1945-7111/abc90c.

[7] Brodyn M S, Starkov V N.Methods of computational physics in the problem of mathematical interpretation of laser investigations [J].Quantum Electronics, 2007, 37(7):679–684.DOI:10.1070/QE2007v037n07ABEH013493.

[8] Ray D, Pinti O, Oberai A. Deep Learning and Computational Physics (Lecture Notes)[J].ArXiv, 2023, abs/2301.00942.DOI:10.48550/arXiv.2301.00942.

[9] Yu P, Lauder G V. Combining Computational Fluid Dynamics and Experimental Data to Understand Fish Schooling Behavior[J]. Integrative and Comparative Biology, 2024.DOI:10.1093/icb/icae044.

[10] Carrillo J A, Gamba I M, Majorana A, et al. 2D semiconductor device simulations by WENO-Boltzmann schemes: Efficiency, boundary conditions and comparison to Monte Carlo methods[J].Journal of Computational Physics, 2006, 214(1):55-80.DOI:10.1016/j.jcp.2005.09.005.