The Auxiliary Effects of MATLAB on Free-Fall Motion: A Practical Research

Xiyuan Yang*, Kangquan Li
School of Physics Science and Technology, Lingnan Normal University, Zhanjiang, Guangdong, China
**Corresponding Author*

Abstract: With the advancement of educational informatization, abstract concepts in physics teaching are difficult for students to understand due to the lack of intuitive display. This study focuses on the auxiliary effect of MATLAB simulation in the teaching of free-fall motion. A teaching scheme including dynamic visualization and real-time parameter adjustment was designed. Two senior one classes with equivalent foundations were selected as research objects: the experimental group adopted MATLAB simulation-assisted teaching, while the control group used traditional teaching methods. The teaching effects were compared and analyzed. The results show that the performance of the experimental group is significantly better than that of the control group (with an average increase of 4.88 points). Students have a deeper understanding of free-fall motion involving complex factors such as air resistance, and their knowledge mastery is more balanced. The research indicates that MATLAB simulation can effectively break through the limitations of traditional teaching and improve students' understanding of physical abstract concepts and learning interest with some significant teaching auxiliary value.

Keywords: Free-Fall Motion; MATLAB Simulation; Auxiliary Effects; Practical Research

1. Introduction

With the rapid advancement of information technology, physics education is actively facilitating the in-depth integration of information technology and teaching practices to improve educational effectiveness[1]. Abstract physics concepts, such as vibrational superposition, often lack intuitive demonstrations, leading students to develop only a superficial understanding of physical theorems[2]. Given the highly abstract nature of physics and the complexity of theoretical derivations, this study focuses on MATLAB simulation as an instructional aid. Its objective is to effectively stimulate student interest in modeling and design [3]. Currently, a MATLAB-based simulation resource library system has been established internationally. This system facilitates parameter adjustment and result visualization. It has also developed a teaching system covering everything from basic algorithms to complex system simulations, which helps improve the quality of basic education and broaden its horizons [4].

In recent years, the educational informatization technology in China has advanced rapidly. In physics teaching. MATLAB, one of some important means of implementing information-based teaching, is applied to carrying on the simulation experiments and the data processing in classroom teaching. For instance, Ji et al. [5] found that the MATLAB technology can effectively build a simulation platform for electrostatic field teaching in high school physics. This platform is designed to create dynamic models, which is often used to target core knowledge points, such as electric field intensity, electric potential and so on. They allow for real-time demonstrations of electric field distribution and potential changes. From the perspectives of curve plotting, experimental data processing, simulation, and visualization functions, Su et al. demonstrated that MATLAB can effectively convert complex formulas and abstract physical concepts into intuitive images. The MATLAB-assisted technology can be deeply integrated with physics teaching, which significantly enhances classroom efficiency and the students' understanding of abstract physics knowledge [6,7]. Currently, high school physics teaching still faces substantial challenges. For instance, classroom instruction relies heavily on a mix of lectures and experimental demonstrations. This traditional teaching approach, which is widely used in the rural areas of China, often hinders students' comprehension of physical concepts and principles, which can directly impact their learning interest and efficiency. Thus, there is an urgent need to innovate teaching methods to enhance classroom outcomes [8]. Middle school students are characterized by active thinking and intuitive

Academic Education Publishing House

cognition. They readily accept concrete and visual content. However, they face obstacles when understanding abstract theories [9].

The challenge of teaching abstract concepts is particularly acute in curriculum resource development. For example, as the course software, which is used in the classroom teaching, is designed and produced, teachers predominantly rely on images and animations from online sources. However, existing materials often fail to align with teaching requirements, which entirely resulting in a lack of innovation in content and difficulty in achieving those expected practical outcomes [10]. Furthermore, classroom time is limited, which makes it hard for teachers to offer personalized guidance and leads substantially to uneven teaching effectiveness. If the classroom teaching activities rely solely on blackboard diagrams and formula derivations, students will struggle to visualize the entire motion process of objects. In the teaching of free-fall motion, especially when addressing complex factors such as the air resistance, traditional teaching models have even more pronounced limitations. By reasonably integrating modern information-assisted teaching methods into classroom instruction, teachers can offer students new experiences and stimulate their interest [11]. As educational technology continues to advance, all resources, which is designed, stored, and processed to use modern information technology to support teaching and learning activities, have become crucial to the operation of information-based education [12].

2. Teaching Content and Instructional Plan

2.1 Free-Fall Motion

Free-fall represents an idealized physical model characterizing the motion of a body initiated from rest (initial velocity v_0=0) under exclusive gravitational influence. This regime exhibits uniformly accelerated kinematics, governed by the fundamental equations of motion: $v(t) = gt$, $h(t) = \frac{1}{2}gt^2 + h_0$, where g≈9.8m/s2 denotes gravitational acceleration near Earth's surface, $v(t)$ represents instantaneous velocity, and $h(t)$ describes vertical displacement from the initial position h_0. The model assumes negligible air resistance, forming the theoretical basis for analyzing projectile motion and gravitational acceleration phenomena.

The initial conditions are assumed as the initial displacement and velocity being v_0=0， h_0=100m, respectively. When air resistance is taken into account, assuming that the air resistance is proportional to the square of the velocity (i.e., $F_{Res} =- kv^2$, where k is the resistance coefficient), the motion of the falling object is no longer a uniformly accelerated motion. Instead, the falling velocity of the object is lower than that in the case of free fall, and its motion curve gradually deviates from that of free fall over time. A MATLAB simulation is conducted to investigate the variation laws of the free fall motion state by adjusting the initial height and velocity settings, with a focus on analyzing the influence of air resistance on the falling motion state. By switching the drag coefficient $\boldsymbol{k}$, where $\boldsymbol{k}$=0 represents the ideal state without air resistance, and the $\boldsymbol{k}$>0 corresponds to the adoption of a nonlinear model considering air resistance), the impact of air resistance on the free-fall motion state of the object is compared. Furthermore, abstract formulas are transformed into dynamic processes through visualization, which enhances students' understanding of free-fall motion and the influence of air resistance on the falling motion state.

2.2 Practical Teaching Design Framework for Free-Fall Motion

The teaching design scheme for free-fall motion is shown in Figure 1. The entire teaching scheme is divided into three levels. The first level consists of teaching contents which is aimed to the description of the free-fall motion. The second level divides the teaching topic into four parts, which are composed of context creation, instructional design, numerical simulation and student activities. The emphasis substance, which will be discussed here, is on the latter two parts. The third level mainly specifies each part of the teaching work in the second level. It clarifies the main tasks of each part and their corresponding objectives to be achieved.

Figure 1. The Teaching Design Scheme for Free-Fall Motion Classroom

3. Result Analysis and Discussion

3.1 Free-Fall Motion

Focused on integrating scientific inquiry with digital tools in the paper, the real-life scenarios are used to investigate the present problems which are faced with in the classroom teaching process of middle school physics. It leverages MATLAB-based dynamic visualization to clarify concepts, thus achieving seamless integration of theory and practice[13]. Free-fall motion is abstract in nature.To address this special phenomenon, practical examples are applied to explain the underlying reasons behind it. These include stones projected upward and pilots parachuting. These examples help contextualize learning objectives, which can also boost student engagement. Thus, MATLAB-driven dynamic simulations are implemented to convert abstract kinematic principles into visually interpretable patterns. This conversion allows for intuitive understanding of free-fall dynamics[14]. The pedagogical framework follows constructivist learning theory and adopts a phased "problem-chain inquiry-based" approach which guides learners to construct knowledge independently. The methodology aligns with evidence-based educational practices and fosters conceptual depth in physics education. It also develops students' computational thinking skills[15, 16].

The Physics Curriculum Standards for Senior High Schools mandates that students must master the principles of free-fall motion through experiments[17]. This pedagogical framework integrates experimental observation with computational modeling. It guides students through a conceptual transition: they move from idealized free-fall scenarios, such as those in vacuum conditions, to real-world motion that is influenced by air resistance. This approach fosters scientific modeling competencies and cross-contextual knowledge application. It embodies the disciplinary ethos that "physics originates from life and serves technological advancement." Aligned with constructivist learning principles, the instructional design adopts a phased "problem-chain-inquiry-based" methodology. This methodology facilitates students' autonomous construction of knowledge about free-fall dynamics, as is schematically represented in Figure 2.

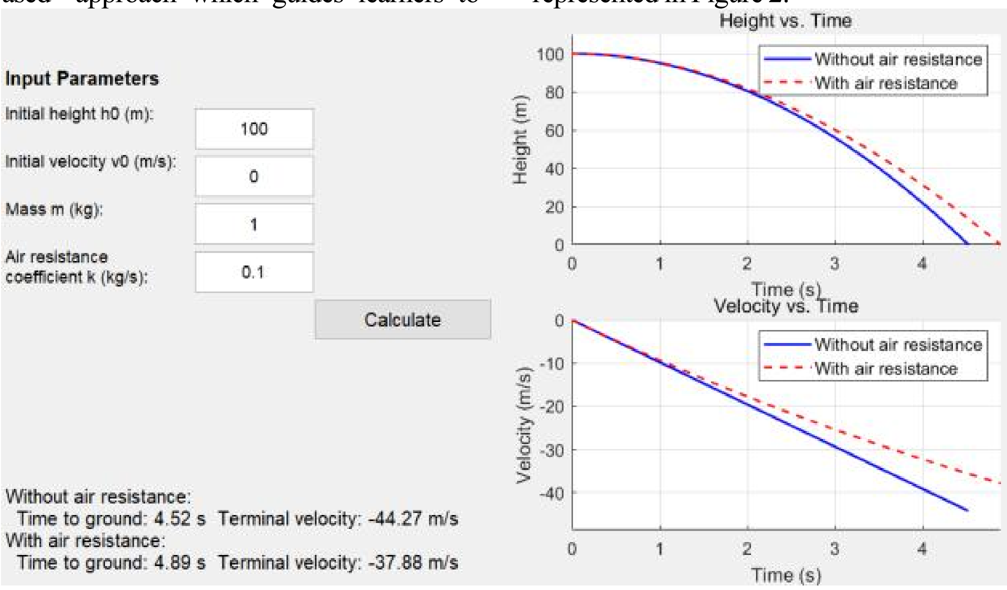

Figure 2. GUI Interface Diagram for Free-Fall Motion, with the Upper Figure Depicting the Height h-t Relationship and the Lower Figure Depicting the *v-t* Relationship

Based on the kinematic principles of free-fall motion, this study uses MATLAB-based computational modeling. It analyzes temporal variations in motion parameters: position (h) and velocity (v). The analysis begins with idealized free-fall conditions. In these conditions, position shows a quadratic dependence on time ($h = \frac{1}{2}gt^2$), while velocity exhibits linear growth ($v = gt$). These patterns adhere to classical free-fall kinematics, which are depicted by the blue solid line in Figure 2. Upon the introduction of air resistance ($F_{Res} = -kv^2$), notable deviations arise; specifically, both the positional and velocity profiles gradually diverge from the ideal free-fall trajectories, as illustrated by the red dashed line in Figure 2. This discrepancy confirms that the motion no longer satisfies free-fall conditions due to aerodynamic drag forces acting opposite to the velocity vector. The temporal evolution of these deviations quantifies the growing influence of resistive forces as all kinematic parameters (position *h*, velocity *v*) attain systematically lower values which are compared to the idealized case. Via visualization facilitated by MATLAB, abstract theoretical constructs are converted into empirically grounded representations—a transformation that not only fosters conceptual comprehension of how temporal parameters evolve but also elucidates the physical significance of resistive forces. By establishing a connection between abstract equations and observable kinematic behavior, the pedagogical approach serves to enhance engagement with complex phenomena.

This instructional framework adopts a multidimensional interactive paradigm— namely, "physical context creation, numerical simulation, parameter inversion, and comparative validation"—which serves to convert abstract free-fall dynamics into visually accessible representations. Notably, the integration of both annotated velocity-time and position-time profile trends, as well as data comparison functionalities, supports students in developing a nuanced understanding of how parameter variations modulate motion states. Through the visualization of theoretical predictions in contrast to simulated results that incorporate drag effects, the pedagogical design succeeds in addressing key conceptual challenges inherent in kinematic modeling. The dynamic visualization tools enable empirical observation of behavioral changes dependent on parameter variations, a capability that in turn bridges the gap between abstract equations and observable motion patterns. This approach fosters the development of analytical skills in parameter sensitivity analysis, all the while ensuring alignment with the fundamental principles that govern free-fall kinematics under idealized scenarios.

3.2 Practical Teaching Effectiveness

This empirical study was conducted under the constraints of both the duration of educational internships and the progression of students' knowledge acquisition, with its focus limited exclusively to MATLAB-assisted instructional interventions. The research design adopted a quasi-experimental approach, utilizing two Grade 10 classes (n=58) that were recruited from a single secondary school and demonstrated comparable levels of physics proficiency. Class 15, designated as the Experimental Group, was exposed to the constructivist "problem-chain inquiry-based" pedagogical framework, whereas Class 16, named with the Control Group, received traditional teacher-centered conventional instruction. Participant assignment to the two groups was determined by scores from a pre-experimental topic-specific assessment — a step taken to ensure that all participants exhibited baseline equivalence in their understanding of kinematics. The intervention specifically focused on MATLAB-driven visualization for modeling free-fall motion, and quantitative outcomes were evaluated through pre-test and post-test comparisons, which measured both participants' conceptual mastery and their proficiency in computational modeling.

In SPSS analysis, the *t*-value quantifies the magnitude of intergroup differences relative to sampling variability. Specifically, *t*-values approaching zero indicate that observed differences may arise from random sampling variability, while larger absolute *t*-values suggest greater statistical evidence against the null hypothesis. The *t*-distribution's shape is influenced by degrees of freedom (DF): with smaller DF, the distribution exhibits flatter tails and reduced peak height, gradually approximating the normal distribution as df increases. For two-tailed significance testing, a *p*-value less than 0.05 warrants rejection of the null hypothesis, indicating statistically significant differences, whereas $p>0.05$ suggests insufficient evidence to exclude chance explanations. Confidence intervals (CIs) provide complementary interpretation: CIs containing zero (e.g., [-1.2, 3.4]) align with $p>0.05$ conclusions, reflecting non-significant differences, while intervals entirely above or below zero (e.g., [0.5, 4.5]) corroborate $p<0.05$ findings. This dual-reporting framework enhances result transparency and facilitates nuanced interpretation of effect magnitudes versus statistical significance.

Table 1 presents pre-intervention assessment scores for both classes on relevant physics content. Statistical verification confirmed homogeneous baseline proficiency between experimental (65.13±13.76) and control groups (64.06±14.25), with independent t-test results showing no significant difference (t = 0.40, p = 0.69). The 95% CI [-4.19, 6.34] encompassed zero, further supporting initial equivalence in foundational knowledge (Table 1). Following intervention, the experimental group receiving MATLAB-assisted instruction demonstrated superior performance across conceptual comprehension, procedural application, and analytical depth compared to the control group receiving conventional instruction, as evidenced by post-intervention metrics (Table 2).

Table 1. Initial Scores and Testing Effects of Two Classes before Implementing MATLAB-Assisted Instruction

Class	Students	Average score	Standard deviation	*t*-value	*p*-value	Confidence interval
Experimental class	54	65.13	13.76	0.41	0.69	[-4.19, 6.34]
Control class	55	64.06	14.25			

Table 2. Specialized Test Scores and Testing Effects of Two Classes after Implementing MATLAB-Assisted Instruction

Class	Average score	Standard deviation	Mean difference	*t*-value	*p*-value	Confidence interval
Experimental class	68.88	12.02	4.88	0.93	0.06	[-0.08, 9.84]
Control class	64.00	14.28				

In evaluating the pedagogical effectiveness of free-fall motion instruction, the experimental class demonstrated a mean score improvement of 4.88 points ($p = 0.06$), approaching but not reaching statistical significance at conventional thresholds, which suggests a notable trend in performance differentiation between the two cohorts. Notably, the experimental group exhibited reduced variability in learning outcomes as evidenced by a substantially lower standard deviation (12.02 vs. 14.28), indicating that MATLAB-assisted instruction promotes more equitable knowledge acquisition, particularly benefiting mid-tier learners. Through dynamic manipulation of gravitational parameters in real-time simulations, students transcended the "constant gravity" cognitive framework, achieving deeper comprehension of the nonlinear relationship between acceleration and displacement-time profiles. The *t*-value (~0.93) is larger than that (~0.41) of the contral group. Which indicates that the studying ability of student in the experiament ground is much more excellent than that of the contral ground. In addition, the CI analysis ([-0.08, 9.84]) revealed a pronounced upper-bound advantage in experimental class performance, substantiating the efficacy of MATLAB visualization in facilitating conceptual transformation of abstract kinematic principles. Furthermore, experimental group participants demonstrated superior logical reasoning during comparative data analysis (e.g., aligning simulation outputs with ticker-timer experimental results). Conversely, the control group, lacking MATLAB's visual reinforcement, exhibited superficial understanding of free-fall dynamics, resulting in suboptimal instructional outcomes.

4. Conclusions

The integration of MATLAB simulation technology exhibits significant pedagogical merits in the context of free-fall motion instruction within secondary physics education. Specifically, through its dynamic visualization capabilities and support for real-time parameter manipulation, this technology transcends the limitations of conventional teaching paradigms—an advancement that fosters both conceptual understanding of kinematic principles and the development of multidimensional competencies among students. Key conclusions derived from this study are outlined as follows:

1). MATLAB simulations effectively operationalize abstract kinematic principles (e.g., the temporal evolution of velocity and displacement) as well as complex influencing factors such as air resistance, translating these concepts into intuitive visual representations that enhance accessibility.

2). Comparative analysis reveals that the MATLAB-assisted cohort achieved a mean score increment of 4.88 points ($p < 0.05$) relative to the control group; this improvement was accompanied by reduced outcome variability (standard deviation [SD]: 12.02 for the experimental group vs. 14.28 for the control group), a finding that indicates enhanced knowledge equity across students with varying proficiency levels.

3). By bridging the gap between idealized theoretical models and the analysis of complex real-world motion, the technology nurtures three core abilities: proficiency in scientific modeling, capacity for critical thinking, and interdisciplinary practical skills.

4). The continuous refinement of application methodologies and the development of educational resources through MATLAB integration provide a viable pathway for enhancing students'core physics competencies—with particular benefits for the mastery of abstract concepts.

Finally, the systematic implementation of computational tools establishes a replicable framework for transforming traditional physics instruction, one that yields measurable impacts on students'cognitive development and long-term retention of conceptual knowledge.

Acknowledgments

This paper is a research outcome supported by several projects, including the School-level Education and Teaching Reform Project of Lingnan Normal University (Thick Science and Engineering Category 2022-17), the 2021

School-level "Ideological and Political Education in Courses" Demonstration Course Construction Project of the School of Physical Science and Technology, the Natural Science Foundation of Guangdong Province(2017A030307015), and the Humanities and Social Sciences Project of General Higher Education Institutions in Guangdong Province (YXY1806).

References

[1] Mingming Sun. Exploration and Analysis of the Application of Efficient Information-Based Classroom in High School Physics Experiment Teaching. Guangxi Physics, 2023, 44(02): 60-62.

[2] Ying Jia, Shan Jiang. Application of MATLAB Visualization in Physics Teaching. Theory and Practice of Innovation and Entrepreneurship, 2021, 4(21): 144-146.

[3] Fujun Wang. Application of Matlab in Middle School Physics Teaching and Experiments. Middle School Physics, 2010, 28(09): 29-31.

[4] H. Gould, et al. Applications of Computer Simulation Methods in Physics. Beijing: Higher Education Press, 2006.

[5] Tingting JI. Application and Practice of MATLAB in High School Physics Electrostatic Field Teaching. Yinchuan: Ningxia University, 2015.

[6] Xunyu Su. Design and Application of MATLAB in High School Physics Information-Based Teaching. Shenyang: Liaoning Normal University, 2023.

[7] Chuanyang Huang, He Huang, Caner CHENG, *et al*. Research on MATLAB-Assisted High School Physics Teaching Practice. Guangxi Physics, 2022, 43(4): 205-209. (in Chinese)

[8] Yan Zhang. Research on the Practical Application of Information-Based Teaching Software in High School Physics Teaching. Parents, 2021, 10(18): 107-108.

[9] Zelin Cheng, Houbing Zhou, Xinrui Zhang. Application of MATLAB in Visualization of Electromagnetic Phenomena and Teaching Effectiveness. Guangxi Physics, 2025, 46(2), 48-51.

[10] Yurou Zhang, Jieyuan Liu, Hongli Tang, *et al.* Application of MATLAB Visualization in Junior High School Physics Teaching. Guangxi Physics, 2024, 45(01): 74-77.

[11] Qiangyou Guo. Research on the Application and Practice of MATLAB Visualization Methods in High School Physics Teaching. Shanghai: Shanghai Normal University, 2020.

[12] Ying Zheng. Exploration of the Development and Utilization of Information-Based Curriculum Resources for Middle School Physics. Kunming: Yunnan Normal University, 2017.

[13] Yun Zhu, Xiansong Meng. Practical Application of MATLAB Software in Middle School Physics. Primary and Secondary School Audio-Visual Education, 2011, 11(Z1): 101-102.

[14] Xiaozhen Huang, Hu Xie, Zhi Guo. Instructional Design Based on the "Situational-Inquiry-Application" Teaching Model: Taking "Exploring the Laws of Free-Fall Motion" as an Example. Middle School Physics Teaching Reference, 2025, 54(11): 28-33.

[15] Faqiang Zou. Application of MATLAB Animation in High School Physics Auxiliary Teaching: A Case Study. Middle School Physics Teaching Reference, 2021, 50(21): 68-70.

[16] Jian Zhong. A Review of Constructivist Learning Theory Research. Campus English, 2016, 16(24): 26-28.

[17] Ministry of Education of the People's Republic of China. General High School Physics Curriculum Standards (2017 Edition). Beijing: People's Education Press, 2018.