

INNOVATIVE MODELS OF VISUAL LEARNING IN PHYSICS EDUCATION DURING DIGITAL TRANSFORMATION: A CASE STUDY OF SPECIALIZED MILITARY SCHOOLS

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Abstract. This article develops and substantiates an innovative visual-learning framework for teaching physics in specialized military schools during digital transformation. The study follows a theoretical-analytical and design-based case-study approach grounded in national policy documents on educational digitalization, research on interactive simulations, computational modeling, multimedia learning, cognitive load, and LMS-based analytics. The central argument is that, in a military-academic context, physics should be taught not as a static body of formulas but as a model-based language for describing motion, constraints, uncertainty, and decision-making. The paper proposes three interrelated visual-learning models: (1) dynamic simulation-based conceptualization, (2) multi-representational computational modeling, and (3) LMS-embedded interactive visual assessment. Mechanics and introductory ballistic trajectory tasks are used as demonstrative cases because they require synchronized qualitative reasoning, mathematical formalization, and algorithmic verification. The analysis shows that visual models become pedagogically productive when they reduce invisible processes to inspectable structures, support guided inquiry, and provide immediate feedback through dashboards and interactive content. The resulting framework is suitable for Temurbek specialized military schools and similar institutions seeking to align subject teaching with engineering reasoning, digital didactics, and evidence-based instructional design.

Keywords: visual learning, physics education, digital transformation, specialized military schools, computational modeling, LMS, interactive simulations.

Аннотация. В данной статье разрабатывается и обосновывается инновационная визуально-обучающая модель преподавания физики в специализированных военных школах в условиях цифровой трансформации. Исследование основано на теоретико-аналитическом и проектно-кейс-ориентированном подходе, опирающемся на национальные нормативные документы по цифровизации образования, исследования в области интерактивных симуляций, вычислительного моделирования, мультимедийного обучения, когнитивной нагрузки и аналитики на основе LMS-систем. Центральная идея статьи заключается в том, что в военно-академическом контексте физика должна преподаваться не как статический набор формул, а как модельно-ориентированный язык описания движения, ограничений, неопределённости и процессов принятия решений. В статье предлагаются три взаимосвязанные визуально-обучающие модели: (1) концептуализация на основе динамических симуляций, (2) многопредставленческое вычислительное моделирование и (3) встроенное в LMS интерактивное визуальное оценивание. В качестве демонстрационных примеров используются задачи по механике и начальной баллистической траектории, поскольку они требуют синхронизированного качественного анализа, математической формализации и алгоритмической верификации. Анализ показывает, что визуальные модели становятся педагогически эффективными тогда, когда они преобразуют невидимые процессы в доступные для анализа структуры, поддерживают управляемое исследовательское обучение и обеспечивают мгновенную обратную связь через панели мониторинга и интерактивный контент. Разработанная модель подходит для специализированных военных школ «Темурбеклар мактаби» и аналогичных образовательных учреждений, стремящихся согласовать предметное обучение с инженерным мышлением, цифровой дидактикой и доказательно-ориентированным проектированием обучения.

Ключевые слова: визуальное обучение, преподавание физики, цифровая трансформация, специализированные военные школы, вычислительное моделирование, LMS, интерактивные симуляции.

***Annotatsiya.** Ushbu maqolada raqamli transformatsiya sharoitida ixtisoslashtirilgan harbiy maktablarda fizika fanini o'qitish uchun innovatsion vizual-ta'lim modeli ishlab chiqiladi va asoslanadi. Tadqiqot ta'limni raqamlashtirish bo'yicha milliy siyosiy hujjatlar, interaktiv simulyatsiyalar, hisoblash modellashtirish, multimedia ta'limi, kognitiv yuklama hamda LMS asosidagi analitik tadqiqotlarga tayangan holda nazariy-tahliliy va design-based case-study yondashuvi asosida olib borilgan. Maqolaning markaziy g'oyasi shundan iboratki, harbiy-akademik kontekstda fizika statik formulalar majmui sifatida emas, balki harakat, cheklovlar, noaniqlik va qaror qabul qilish jarayonlarini tavsiflovchi modelga asoslangan til sifatida o'qitilishi zarur. Maqolada o'zaro bog'liq uchta vizual-ta'lim modeli taklif etiladi: (1) dinamik simulyatsiyalarga asoslangan konseptualashtirish, (2) ko'p reprezentatsiyali hisoblash modellashtirish va (3) LMS tizimiga integratsiyalashgan interaktiv vizual baholash. Mexanika hamda boshlang'ich ballistik trayektoriya masalalari namoyishiy misollar sifatida tanlangan, chunki ular sifatli mantiqiy tahlil, matematik formallashtirish va algoritmik verifikatsiyani uyg'un holda talab qiladi. Tahlillar shuni ko'rsatadiki, vizual modellar ko'rinmas jarayonlarni kuzatiladigan strukturalarga aylantirganda, yo'naltirilgan tadqiqot faoliyatini qo'llab-quvvatlaganda hamda dashboard va interaktiv kontent orqali tezkor feedback taqdim etganda pedagogik jihatdan samarali bo'ladi. Ishlab chiqilgan model Temurbeklar maktablari va shunga o'xshash ta'lim muassasalarida fan o'qitishni muhandislik tafakkuri, raqamli didaktika va evidence-based instructional design tamoyillari bilan uyg'unlashtirish uchun xizmat qiladi.*

***Kalit so'zlar:** vizual ta'lim, fizika ta'limi, raqamli transformatsiya, ixtisoslashtirilgan harbiy maktablar, hisoblash modellashtirish, LMS, interaktiv simulyatsiyalar.*

Introduction. Specialized military schools operate at the intersection of general secondary education, pre-professional orientation, disciplined learning culture, and technology-intensive training. In such institutions, physics has a strategic curricular role because it underpins mechanics, optics, electronics, navigation, sensing technologies, and engineering reasoning. The Temurbek schools in Uzbekistan exemplify this profile: they are military-academic schools that combine general education with a future-oriented training logic in which analytical thinking, responsibility, and rapid decision-making are educational priorities.

Under these conditions, teaching physics through static explanation and routine substitution into formulas is pedagogically insufficient. Learners who are expected to function in technically complex and operationally dynamic environments need to understand how a physical system behaves when parameters, constraints, and assumptions change. They must be able to move from a verbal scenario to a formal model, from a formal model to a simulation, and from a simulation to a justified conclusion. This requirement makes visual learning more than a motivational supplement; it becomes an epistemic instrument for disciplined reasoning.

Digital transformation amplifies this need. Educational reforms increasingly emphasize digital infrastructure, interactive content, learning management systems, and data-informed teaching. However, the mere presence of digital tools does not guarantee conceptual gain. In physics education, the decisive issue is whether digital resources enable students to see invisible processes, connect equations with motion, manipulate variables meaningfully, and test the validity of their own assumptions.

Therefore, the purpose of this article is to formulate an innovative model of visual learning in physics for specialized military schools, using mechanics as the core case. The article synthesizes research on simulations, computational modeling, multimedia learning, and LMS integration, and translates that synthesis into an instructional architecture appropriate for a military-school environment.

Literature review. The literature on digital physics education consistently shows that interactive visual environments can improve conceptual understanding when they are used as guided cognitive tools rather than decorative media. De Jong and van Joolingen demonstrated that computer simulations are especially powerful in discovery-oriented learning environments, yet the benefits depend on support structures that direct attention, scaffold inquiry, and connect observation to explanation. Adams likewise argues that interactive simulations are most effective when they help learners inspect hidden mechanisms and are embedded in purposeful instructional guidance.

Research on PhET provides strong support for simulation-based visual learning. Wieman, Adams, and Perkins describe simulations as environments that allow learners to manipulate variables, observe consequences instantly, and build intuition about physical systems. Finkelstein and colleagues further showed that, in some contexts, virtual environments can outperform physical equipment for conceptual learning because simulations strip away irrelevant complexity and focus attention on the underlying phenomenon. These findings are especially relevant for mechanics, where kinematics, force interaction, and trajectory structure often remain cognitively fragmented in conventional classroom explanations.

The multimedia learning tradition explains why visual-learning models work when properly designed. Mayer's theory emphasizes the coordinated use of verbal and pictorial channels, while Sweller's cognitive load framework warns against overloading learners with extraneous signals, visual noise, or uncontrolled complexity. In other words, an effective visual-learning model is not simply rich in media; it is selective, coherent, and aligned with the knowledge structure students are expected to construct.

A second major strand of research concerns computational modeling. Caballero, Kohlmyer, and Schatz showed that introducing computation into mechanics changes the nature of student problem solving: students must define state variables, iterate numerical rules, diagnose model failures, and interpret output. Vieyra and colleagues extend this logic by proposing a framework in which computational modeling becomes an integral part of physics teaching rather than an isolated programming add-on. This line of work is central for specialized military schools, where engineering-oriented reasoning requires learners to work with uncertainty, approximation, and model verification.

Finally, digital learning environments increasingly rely on LMS ecosystems and interactive content tools. H5P integration in Moodle allows simulations, branching tasks, embedded questions, and analytics to be combined within a single learning trajectory.

Rahmi, Fajri, and Azrul report a positive correlation between students' H5P-supported learning experience and learning outcomes, while recent systematic review evidence indicates that digital simulations are associated with gains in engagement and conceptual learning across STEM settings. Together, these studies justify a model of visual learning that combines simulation, computation, structured inquiry, and platform-based feedback.

Table 1. Core visual-learning tools and their didactic functions in physics education

Tool category	Typical representation	Instructional function	Military-school relevance
Interactive simulation	Animated variables, vectors, sliders	Conceptualization of hidden processes	Supports rapid interpretation of changing conditions
Computational model	Equations, numerical iteration, code	Formalization and verification	Develops engineering-style reasoning
H5P/LMS activity	Interactive quiz, branching task, embedded prompt	Guided assessment and reflection	Tracks individual learning trajectories
GeoGebra visualization	Graphs, dynamic geometry, parameter control	Multi-representational linking	Connects mathematics with physical interpretation

Methodology. This study adopts a theoretical-analytical and design-based case-study methodology. The case is not a statistical sample but a pedagogical design problem: how should physics instruction be organized in specialized military schools so that visual learning supports disciplined conceptual reasoning and engineering-style problem solving? The methodological logic integrates policy analysis, literature synthesis, physics modeling, and instructional design.

The proposed framework is organized into three interconnected visual-learning models. Model 1, dynamic simulation-based conceptualization, is used to make invisible processes visible. Students begin with a physical question such as why a projectile path changes when launch angle varies, or why friction may prevent motion even when a slope appears steep. In this phase, simulation is used to produce conceptual contrast, cognitive conflict, and guided observation.

Model 2, multi-representational computational modeling, translates visual intuition into formal structure. Learners construct or interpret equations such as $x(t)=v_0\cos\alpha\cdot t$ and $y(t)=h_0+v_0\sin\alpha\cdot t-gt^2/2$ for ideal projectile motion, and then compare these with numerical update rules when drag or other non-ideal factors are introduced: $v_x(t+\Delta t)=v_x(t)+a_x\Delta t$, $v_y(t+\Delta t)=v_y(t)+a_y\Delta t$, $x(t+\Delta t)=x(t)+v_x\Delta t$, $y(t+\Delta t)=y(t)+v_y\Delta t$. The instructional aim is to synchronize equations, graphs, tables, and animated trajectories.

Model 3, LMS-embedded interactive visual assessment, ensures that learning remains traceable and individualized. Before class, students complete a diagnostic quiz that identifies misconceptions. During class, H5P-based checkpoints interrupt the

simulation sequence and require prediction, explanation, or parameter selection. After class, students submit a short reflective report that explains not only the numerical answer but also the modeling assumptions and why a particular solution is acceptable under specific constraints.

From a didactic perspective, the methodology rests on four principles: guidance over unguided exploration, visibility of hidden processes, comparison of ideal and non-ideal models, and assessment of reasoning rather than answer reproduction. These principles are especially suitable for military-school education because they train students to justify conclusions under variable conditions rather than memorize context-free formulas.

Table 2. Architecture of the proposed visual-learning framework

Phase	Teacher action	Student action	Digital environment
Pre-class diagnosis	Assign misconception-focused quiz	Reveal prior conceptions	LMS + H5P
Conceptual visualization	Launch guided simulation scenario	Predict and observe	PhET / GeoGebra
Computational extension	Translate the scenario into equations and update rules	Compare analytic and numerical models	Notebook / scripted environment
Reflective assessment	Request explanation and justification	Interpret results and assumptions	LMS submission + dashboard

Results. The analytical results of the proposed framework can be described at two levels: evidence from prior empirical research and evidence from modeled mechanics cases. At the empirical level, Hake's large-scale comparison found substantially higher normalized gains for interactive-engagement instruction than for traditional instruction. Wieman and colleagues reported that students working with PhET simulations in specific physics topics could achieve markedly stronger conceptual performance than students taught through conventional exposition alone. Rahmi and co-authors found a statistically significant positive correlation ($r = 0.503$, $p = 0.000$) between H5P-supported learning experience and achievement in an LMS-integrated environment. Recent systematic review evidence also shows that simulations are consistently associated with improved engagement and learning outcomes in STEM education.

At the modeling level, the first case concerns motion on an incline with friction. The relation $a = g(\sin\theta - \mu\cos\theta)$ demonstrates that motion is governed not by slope angle alone but by the interaction between geometry and surface conditions. For $\mu=0.25$, the critical condition $\tan\theta = \mu$ gives a threshold angle of approximately 14.0° . Thus, a 10° incline does not necessarily produce motion, whereas at 20° the acceleration becomes positive and at 30° it increases substantially. When students visualize this relationship dynamically, they move beyond verbal intuition and learn to interpret a threshold condition as a design-relevant constraint.

The second case concerns projectile motion. In an ideal model with $h_0 = 1.5$ m and $v_0 = 40$ m/s, the range reaches about 164.6 m at 45° . However, once a simple drag term is introduced in a numerical model, the optimal angle shifts downward; in the demonstrative simulation used here, the maximum range emerges around 40° , where the range is approximately 126.0 m, while the 45° case drops slightly to about 124.8 m. This result is instructionally important because it shows students that a mathematically elegant rule may fail once the assumptions of the model change.

A third result concerns representational coherence. When students encounter a single static equation, they often treat it as an isolated symbolic object. In the proposed framework, the same physical event is represented simultaneously as an animation, a coordinate graph, a table of state values, and a compact mathematical model. This synchronization reduces fragmentation and supports transfer: students can explain why the curve bends, how the velocity components evolve, and which parameter causes the observed difference between two runs.

Finally, the LMS layer produces a distinct pedagogical result: it turns visual learning into assessable evidence. The teacher can identify whether a student repeatedly changes launch angle without reflecting, whether misconceptions persist despite visual feedback, and whether written explanations are consistent with the selected model. In this sense, the framework not only improves presentation quality but also changes the logic of assessment from answer checking to model-based reasoning analysis.

Table 3. Demonstrative mechanics results used in the case-study framework

Scenario	Parameters	Observed result	Didactic implication
Inclined motion	$\mu=0.25$, $\theta \approx 14^\circ$ threshold	Motion starts only above the critical angle	Students learn constraint- based reasoning
Projectile, ideal	$h_0=1.5$ m, $v_0=40$ m/s, $\alpha=45^\circ$	Range ≈ 164.6 m	Classic rule emerges under strict assumptions
Projectile with drag	$h_0=1.5$ m, $v_0=40$ m/s, $\alpha \approx 40^\circ$	Range ≈ 126.0 m	Optimal solution shifts in non- ideal conditions
LMS analytics	Interactive checkpoints	Reasoning steps become traceable	Assessment moves beyond final answers

Discussion. Compared with conventional lecture-centered teaching, the proposed visual-learning framework has three major advantages. First, it externalizes hidden dynamics. Forces, vector components, and state changes that are normally inferred indirectly become inspectable. Second, it supports disciplined parameter reasoning: students do not merely observe a moving object but examine how the system reacts to controlled variation. Third, it creates a bridge between conceptual understanding and engineering judgment, which is particularly important in specialized military education.

The notion of pedagogical provocation is also central here. Productive questions such as 'Why is 45° not always optimal?' or 'Why does a body remain at rest on a visible

slope?' generate cognitive tension that must be resolved through model revision. In this framework, visual learning is not used to simplify thinking into passive watching; it is used to make contradictions observable so that students are compelled to reason more rigorously.

At the same time, the framework has implementation conditions. Teachers need methodological competence, not just technical access to software. Too little guidance turns simulation into unguided trial and error; too much guidance reduces it to a scripted demonstration. Likewise, visual richness can become counterproductive if cognitive load is not controlled. Therefore, high-quality digital didactics requires careful sequencing, restrained interface design, and explicit transitions between representation types.

For specialized military schools, these considerations are especially significant. Their curricular mission requires both academic rigor and application-sensitive reasoning. A visual-learning model that combines simulation, computation, and LMS analytics aligns with that mission because it trains learners to interpret physical systems under changing conditions, justify assumptions, and make evidence-based decisions.

Conclusion. This article has argued that innovative visual learning in physics education should be understood as a structured modeling environment rather than a collection of digital illustrations. In specialized military schools, where physics supports engineering reasoning, discipline, and technical judgment, visual learning must connect observation, formalization, computation, and reflective assessment.

The proposed three-model framework—dynamic simulation-based conceptualization, multi-representational computational modeling, and LMS-embedded interactive visual assessment—offers a coherent design for achieving this goal. Its practical value lies in helping teachers organize instruction around parameter variation, ideal/non-ideal comparison, and evidence-based explanation instead of routine answer reproduction. For implementation, specialized schools should establish curated banks of physics simulations, train teachers in computational and visual didactics, embed H5P and analytics into LMS workflows, and assess students with rubrics that reward modeling choices, interpretation quality, and verification strategies. Future research should validate the framework through quasi-experimental classroom studies and extend it to optics, electromagnetism, sensor systems, and AI-supported adaptive learning environments.

References:

1. Adams, W. K. (2010). Student engagement and learning with PhET interactive simulations. *Nuovo Cimento C*, 33(3), 21–32. <https://doi.org/10.1393/ncc/i2010-10623-0>
2. Caballero, M. D., Kohlmyer, M. A., & Schatz, M. F. (2012). Implementing and assessing computational modeling in introductory mechanics. *Physical Review Special Topics – Physics Education Research*, 8(2), 020106. <https://doi.org/10.1103/PhysRevSTPER.8.020106>
3. de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, 68(2), 179–201. <https://doi.org/10.3102/00346543068002179>

4. Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., Podolefsky, N. S., Reid, S., & LeMaster, R. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics – Physics Education Research*, 1(1), 010103. <https://doi.org/10.1103/PhysRevSTPER.1.010103>
5. Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74. <https://doi.org/10.1119/1.18809>
6. Kefalis, C., Skordoulis, C., & Drigas, A. (2025). Digital simulations in STEM education: Insights from recent empirical studies, a systematic review. *Encyclopedia*, 5(1), 10. <https://doi.org/10.3390/encyclopedia5010010>
7. Mayer, R. E. (2020). *Multimedia Learning* (3rd ed.). Cambridge University Press.
8. Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, 19(3), 309–326. <https://doi.org/10.1007/s10648-007-9047-2>
9. President of the Republic of Uzbekistan. (2019). On approval of the concept for development of the public education system of the Republic of Uzbekistan until 2030 (Presidential Decree PF-5712).
10. President of the Republic of Uzbekistan. (2020). On approval of the Digital Uzbekistan–2030 strategy and measures for its effective implementation (Presidential Decree PF-6079).
11. Rahmi, U., Fajri, I., & Azrul. (2024). Effectiveness of interactive content with H5P for Moodle-LMS in blended learning. *Journal of Learning for Development*, 11(1), 66–81.
12. Solvang, L., & Haglund, J. (2021). How can GeoGebra support physics education in upper-secondary school—a review. *Physics Education*, 56, 055011. <https://doi.org/10.1088/1361-6552/ac03fb>
13. Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4
14. Vieyra, R. E., Megowan-Romanowicz, C., Fislser, K., Lerner, B. S., Politz, J. G., & Krishnamurthi, S. (2024). Expanding models for physics teaching: A framework for the integration of computational modeling. *Education Sciences*, 14(8), 861. <https://doi.org/10.3390/educsci14080861>

