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A DIDACTIC MODEL FOR USING VIRTUAL LABORATORIES IN TEACHING BIOLOGICAL PHYSICS AND CONDITIONS FOR ITS IMPLEMENTATION

Turdimukhammad Tusmatov
Shukhrat Gulomov
Andijan State Medical Institute

Abstract
This article develops a didactic model for integrating virtual laboratories into biological physics teaching and specifies the conditions required for its implementation in undergraduate medical education. The virtual laboratory is conceptualized as an organized learning environment connecting a biological problem, a physical model, controlled experimentation, interpretation of evidence, and reflective assessment. The design combines constructive alignment, guided inquiry, and complementary virtual and physical activities. Its outputs comprise a six-component model, six laboratory modules, a staged lesson procedure, assessment indicators, and an implementation framework. A six-week, nonrandomized pretest-posttest evaluation is proposed for an experimental group of 30 students and a control group of 25 students. Because no student observations were provided, the quantitative Results section uses a fully synthetic dataset to demonstrate reporting and analysis, not to claim intervention effectiveness. In this illustration, mean scores increase from 47.70 to 73.70 in the experimental group and from 50.88 to 65.12 in the control group. The baseline-adjusted posttest difference is 11.04 points on a 100-point scale (95% confidence interval, 6.72 to 15.35). These values reflect the specified data-generation assumptions and are not empirical findings. Implementation requires curriculum alignment, scientifically checked simulations, accessible infrastructure, teacher preparation, common assessment standards, and explicit links to physical laboratory work. The proposed model provides a transparent basis for subsequent classroom evaluation; its educational effectiveness remains to be tested using authentic observations.

Introduction

The present model addresses a specific teaching problem: how to connect the mathematical description of a physical process with its biological meaning and the evidence obtained through an experiment. The selected biological physics content includes fluid flow, transport across membranes, bioelectricity, light measurement, and acoustic imaging. For this curriculum design, successful learning means more than substituting numbers into an equation. Students should identify relevant variables, predict a relationship, examine measurements, explain discrepancies, and distinguish the assumptions of an ideal model from the conditions of its biological application.

The conceptual starting point is the integrated virtual-laboratory environment described by Tusmatov and Gulomov [1]. Their clinical engineering model connects learning objectives, simulation objects, problem scenarios, documentation, assessment, and feedback. The present article adapts that

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organizational logic to biological physics rather than reproducing its equipment-maintenance content. In the proposed adaptation, the central learning product is an evidence-based explanation of a biological process, supported by a controlled experiment and an explicit statement of model limitations. The design and assessment arrangements below are proposals developed for this article, not findings reported in the source study.

Published research provides a rationale for considering simulation, but not for assuming universal superiority. Finkelstein et al. [2] reported benefits of a circuit simulation for conceptual understanding and subsequent work with real equipment in an introductory physics setting. De Jong, Linn, and Zacharia [3] examined the different affordances of physical and virtual investigation and argued for purposeful combinations. Kapici, Akcay, and de Jong [4] found benefits of combined laboratory environments in a middle-school electricity study. These settings differ from undergraduate medical education, so their findings justify investigation of the proposed approach rather than establish its effectiveness in biological physics.

The aim is to develop an operational didactic model and define the pedagogical, technological, organizational, and assessment conditions needed to implement it. The article addresses three questions: which components connect virtual experimentation with biological interpretation; how these components can be organized into reproducible lessons; and how a two-group evaluation with 30 experimental and 25 control students could be analyzed. Its contribution is the explicit alignment of physical models, inquiry actions, interpretation criteria, and implementation checks within one teaching sequence.

MATERIALS AND METHODS

The work is a conceptual instructional-design study with a proposed classroom evaluation and a synthetic statistical illustration. The methodological analysis draws on the supplied clinical engineering article [1] and selected published work on simulation and laboratory learning [2-4]. This is a focused design-oriented synthesis, not a systematic review. Constructive alignment informs the correspondence between intended outcomes, learning activities, and assessment [5]. Guided inquiry informs the use of prediction prompts, variable-control questions, and gradually reduced support [6]. Research comparing physical and virtual manipulation also supports treating the form of manipulation as a design choice rather than an automatic determinant of learning [7].

Model development follows four design stages: specification of learning needs and observable outcomes; selection of biological physics modules; preparation of simulation scenarios and learning resources; and alignment of assessment with feedback and implementation requirements. No institutional syllabus, completed observation protocol, student-level dataset, or validated assessment instrument was supplied. Consequently, the module selection and six-week schedule represent a proposed arrangement for local adaptation, not an account of an already implemented course. Table 1 summarizes the design procedure.

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Table 1. Stages in designing the biological physics virtual laboratory

Stage	Design activity	Didactic function	Expected product
Needs and outcomes	Identify target concepts, prerequisite skills, and biological contexts.	Translate content into observable student performance.	Outcome map and assessment blueprint.
Module selection	Match each physical model to a manipulable task and interpretation problem.	Connect theory, investigation, and biological meaning.	Six-module laboratory sequence.
Resource design	Prepare simulations, prompts, data exports, model notes, and report templates.	Support controlled inquiry and examination of evidence.	Reusable scenario and resource package.
Assessment and delivery	Specify scoring anchors, feedback, access, staffing, and implementation checks.	Align evaluation with learning actions and delivery conditions.	Rubric, evaluation plan, and readiness checklist.

The proposed evaluation uses a nonrandomized, two-group pretest-posttest design. The experimental condition comprises 30 students and the control condition 25 students, for a total of 55. Both conditions would cover the same six modules, receive the same core explanations, and complete six 90-minute sessions, totaling 540 minutes. The experimental condition uses the complete virtual-laboratory model; the control condition uses teacher-guided demonstrations, conventional practical tasks, and paper-based analysis without interactive parameter manipulation. Both retain a common physical demonstration or comparison stage. Any future difference would therefore concern the instructional package, not isolate the software alone.

Pretesting is scheduled before the first module and posttesting after the sixth. Instructor contact time, learning objectives, task difficulty, and assessment instructions should be matched. Attendance, additional practice, and deviations from the lesson plan should be recorded rather than assumed equal. Pair work is permitted during learning, but testing and written explanations are individual. Group sizes are fixed by the requested design and are not supported by a power calculation. If the two conditions are delivered as only two intact classes, class membership is confounded with treatment; the evaluation must then be described as exploratory, with additional independently assigned classes required for a stronger causal study.

The proposed primary outcome is a 100-point knowledge-and-application assessment: 20 concept questions worth two points each and three case-based tasks worth 20 points each. Each case awards up to four points for physical explanation, experimental reasoning, data handling, biological interpretation, and evaluation of limitations. The corresponding indicators are presented in Table 3. Parallel test forms should sample the same content and cognitive demands. Prior to authentic use, subject experts should review item relevance and clarity, and independent raters should calibrate case scoring. No reliability coefficient or validation result is claimed because item-level responses and rater judgments are unavailable.

For the numerical illustration, 55 synthetic records were generated using NumPy 2.3.5 and default_rng(20260919). Baseline scores were sampled from a normal distribution with mean 52 and standard deviation 9, first for 30 experimental records and then for 25 control records, and rounded to integers. Experimental posttest scores were generated as 75 + 0.65(pretest - 52) + e; control posttest

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scores as 64 + 0.65(pretest - 52) + e. Independent errors e were sampled from a normal distribution with mean 0 and standard deviation 7, drawing the experimental errors before the control errors. Posttest values were rounded and bounded to 0-100. This is one illustrative realization, with an advantage built into its assumptions, not a simulation-based estimate of expected teaching effectiveness.

The principal illustrative analysis is a baseline-adjusted linear model, following the general logic of analyzing follow-up scores conditional on baseline [8]:

$Posttest_i = \beta_0 + \beta_1(Group_i) + \beta_2(Pretest_i) + \varepsilon_i$

Group is coded 1 for experimental and 0 for control; β_1 is the adjusted between-group difference. The reported 95% confidence interval uses HC3 heteroscedasticity-robust standard errors and a t reference distribution with 52 residual degrees of freedom. Welch comparisons of unadjusted posttest scores and individual gain scores are supplementary. Hedges' g uses the pooled posttest standard deviation and the small-sample correction described in effect-size reporting guidance [9]. Tests are two-sided; supplementary p values are descriptive and unadjusted for multiplicity. Independence is an assumption of this artificial dataset, not a claim about classroom observations. Baseline adjustment does not remove unmeasured confounding in a nonrandomized study.

No students were recruited or tested for this manuscript, and no ethics approval, consent procedure, institution, or teaching date is claimed. Before a real evaluation, the responsible institution should determine the required ethics review, obtain appropriate consent, protect student records, and separate research participation from course grading. Synthetic records must not be relabeled as observed data when the manuscript is revised.

RESULTS

The substantive design outputs are the didactic model, its module sequence, assessment indicators, and implementation conditions. They are presented separately from the numerical example. The model consists of six connected components: target and motivation; conceptual content; digital resources; inquiry activity; assessment and feedback; and organizational support. Their relationship is cyclical: an intended outcome determines the task, the task generates an assessable explanation, and the quality of that explanation determines feedback and the next learning action.

The target-and-motivation component frames each lesson around a biological question that requires a physical explanation. The content component identifies the relevant law, units, variables, assumptions, and range of application. The resource component provides a simulation, an accessible instruction sheet, a parameter log, an exportable dataset, and a report template. These resources are proposed as an integrated package; a video or animation without learner-controlled experimentation does not meet the operational definition used in this model.

The inquiry component requires students to predict, plan, manipulate, record, interpret, and revise. The assessment component evaluates the explanation and its evidential basis rather than rewarding completion of on-screen actions. The organizational component secures teaching time, device access, instructor preparation, technical support, and a physical comparison activity. Feedback links all components: a unit error triggers a measurement task, uncontrolled variation triggers a redesigned experiment, and overinterpretation triggers reconsideration of the model assumptions.

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Table 2. Proposed biological physics laboratory modules

Module	Virtual object	Core inquiry task	Learning product
Measurement and uncertainty	Measuring scale or sensor with repeated readings.	Check units, precision, calibration, and variation.	Measurement table with an uncertainty statement.
Hemodynamics	Idealized vessel-flow simulator.	Change radius or viscosity while holding other inputs constant.	Flow graph and an explanation of model limits.
Membrane transport	Two-compartment diffusion and permeability model.	Compare gradients and membrane selectivity.	Transport graph with a causal interpretation.
Bioelectricity	Passive membrane resistance-capacitance model.	Relate parameter changes to voltage-time behavior.	Explanation distinguishing passive charging from excitation.
Biomedical optics	Virtual absorption measurement and calibration system.	Vary concentration or path length and examine calibration.	Calibration plot with limits on interpretation.
Ultrasound principles	Pulse-echo timing and interface model.	Relate echo delay to depth and inspect assumptions.	Depth calculation and a measurement-limitation statement.

A 90-minute lesson is proposed as a reproducible sequence: 10 minutes for the biological problem and concept activation; 10 minutes for prediction and experimental planning; 30 minutes for guided virtual investigation; 20 minutes for data analysis and comparison with a physical demonstration or instructor-provided measurements; and 20 minutes for an individual report, discussion, and corrective feedback. Support is reduced across modules as students demonstrate competence, rather than withdrawn according to time alone. This schedule is a design specification, not a measured account of classroom activity.

In the hemodynamics module, for example, students investigate the ideal laminar-flow relation $Q = \pi\Delta Pr^4/(8\eta L)$, where Q is volume flow rate, ΔP pressure difference, r tube radius, η dynamic viscosity, and L tube length [10]. They first predict the effect of reducing radius to 80% of its initial value while other parameters remain fixed. The calculated ratio $Q_2/Q_1 = 0.8^4 = 0.4096$ becomes a testable model prediction, not a clinical prognosis. Students then generate a radius-flow series, label the axes and units, and compare the trend with their prediction. Their report must state the assumptions of steady flow, a rigid cylindrical tube, and constant viscosity, and explain why pulsatile flow and compliant vessels require caution when extending the ideal result to living systems.

Assessment is organized around five indicators, using the three descriptive anchors in Table 3. For each case response, zero indicates absent or irrelevant evidence, one corresponds to the low anchor, two to the intermediate anchor, three to a mostly correct response with a limited omission, and four to the high anchor. The resulting case scores contribute up to 60 points to the written assessment; the concept questions contribute the remaining 40. The same indicators can guide formative feedback, but completed simulation logs are not substituted for an independently produced final explanation.

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Table 3. Proposed criteria for evaluating case-based biological physics reasoning

Indicator	Low anchor: 1	Intermediate anchor: 2	High anchor: 4
Physical explanation	Names a law without explaining the relationship.	Explains the main relationship with partial support.	Connects the law, variables, and assumptions coherently.
Experimental reasoning	Changes inputs without a clear comparison.	Selects a relevant variable but needs control prompts.	Justifies a controlled comparison and reproducible procedure.
Data handling	Records incomplete values or omits units.	Produces a usable table or graph with minor errors.	Uses correct units, appropriate graphs, and uncertainty reasoning.
Biological interpretation	Repeats a numerical result without meaning.	Relates the result to a biological process in general terms.	Explains the process using evidence without clinical overclaiming.
Limits and reflection	Treats the simulation as an exact biological replica.	Recognizes a limitation when prompted.	Identifies assumptions, alternative explanations, and an improved test.

The rubric is proposed, not psychometrically validated. Scores 0 and 3 are defined in the preceding paragraph; each case has a maximum of 20 points.

Illustrative quantitative results. All values that follow are calculated from the synthetic dataset described in Materials and Methods. It contains 30 experimental and 25 control records, each with a pretest and posttest score; these are not recruited participants or observed outcomes. Baseline means are 47.70 and 50.88, respectively. The experimental baseline is 3.18 points lower, so the groups should not be described as equivalent on the basis of a nonsignificant preliminary test. Table 4 reports the synthetic means, standard deviations, and between-group comparisons.

The adjusted difference is 11.04 points, with a robust standard error of 2.15 and $t(52) = 5.13$. The supplementary gain-score comparison yields $t(41.20) = 5.43$, while the unadjusted posttest comparison yields $t(50.84) = 3.07$. The latter corresponds to Hedges' $g = 0.82$ using the pooled posttest standard deviation; it is not the standardized version of the adjusted coefficient. The difference between adjusted and unadjusted estimates reflects the baseline imbalance and the modeled baseline-posttest association. Neither the confidence interval nor the small p values establish a real instructional benefit because the data-generating process deliberately includes a group advantage.

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Table 4. Synthetic pretest-posttest results for 30 experimental and 25 control records

Measure	Experimental (n = 30)	Control (n = 25)	Difference, E - C (95% CI)	p value
Pretest, mean ± SD	47.70 ± 10.03	50.88 ± 8.12	-3.18 (-8.09 to 1.73)	0.200
Posttest, mean ± SD	73.70 ± 10.20	65.12 ± 10.41	8.58 (2.97 to 14.19)	0.0034
Gain, mean ± SD	26.00 ± 6.28	14.24 ± 9.18	11.76 (7.39 to 16.13)	< 0.001
Adjusted posttest difference	Baseline-adjusted model	Reference group	11.04 (6.72 to 15.35)	< 0.001

All scores are on a 0-100 scale. The first three rows use Welch comparisons; the last row uses a baseline-adjusted linear model with HC3 robust standard errors. CI = confidence interval; SD = standard deviation. Synthetic results are an analysis illustration, not empirical evidence.

Using provisional achievement bands of below 60, 60-79, and 80-100 points, the synthetic experimental posttest distribution contains 3 low-band records (10.0%), 19 intermediate-band records (63.3%), and 8 high-band records (26.7%). The control distribution contains 7 (28.0%), 15 (60.0%), and 3 (12.0%), respectively. These cutoffs are illustrative reporting categories, not validated thresholds for clinical competence. Their practical meaning would need to be established by reviewing item difficulty, expert standards, and observed performance in an authentic evaluation.

The implementation conditions translate the model into checkable responsibilities rather than a general recommendation to use technology. Table 5 identifies minimum arrangements and evidence that an institution could inspect before or during implementation. The proposal prioritizes accessible two-dimensional simulations and reproducible tasks; immersive graphics are optional and do not replace curricular alignment or scientific checking.

Table 5. Conditions for implementing the didactic model

Condition	Minimum implementation arrangement	Evidence to inspect
Curricular alignment	Match every module to a course outcome, prerequisite, and assessment task.	Outcome-task-assessment mapping.
Scientific and didactic quality	Check equations, units, parameter limits, prompts, and biological assumptions.	Instructor review record and tested scenarios.
Technical access and inclusion	Provide one functioning device per learner or pair, accessible materials, and a tested fallback.	Pre-lesson access check and usable alternative resources.
Teacher preparation	Rehearse scenarios, anticipate misconceptions, and calibrate feedback and scoring.	Lesson plan, rehearsal notes, and scored exemplars.
Assessment and data governance	Use common testing rules, individual outputs, protected identifiers, and transparent criteria.	Assessment protocol, rubric, and approved data-handling plan.
Physical transfer and monitoring	Retain apparatus comparison; record attendance, actual exposure, failures, and deviations.	Physical task record and implementation log.

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A staged implementation begins with one reviewed module and a small usability check that does not make effectiveness claims. The next stage introduces the full sequence with common assessment procedures and a record of actual delivery. Expansion should depend on evidence that tasks function, students can access them, instructors apply the criteria consistently, and physical laboratory links remain intact. No completion rate, usability score, learner-satisfaction percentage, or institutional cost saving is reported here because those observations have not been collected.

DISCUSSION

The model relocates instructional attention from the interface to the student's reasoning. Its proposed mechanism is that predictions make prior explanations visible, controlled parameter changes create interpretable comparisons, and reflection connects a numerical pattern to its biological meaning. These are hypotheses about how the model may work, not measured mediators. The decision to include explicit guidance is consistent with Lazonder and Harmsen's synthesis of inquiry-learning research [6], while alignment between outcomes and the assessed explanation follows Biggs [5]. A future evaluation should examine the quality of student explanations and task logs, not only total scores.

The proposal also treats virtual and physical laboratories as complementary rather than mutually exclusive. Circuit research [2] shows that transfer from simulation to real apparatus can occur in a particular instructional setting, while research on combined laboratories [4] supports examining their sequencing. However, these findings cannot guarantee transfer to membrane transport, biomedical optics, or medical instrumentation. In the proposed course, manipulating equipment, detecting contact problems, and confronting real measurement variation require dedicated physical activities. A separate apparatus-based task would therefore be needed before claiming practical skill transfer; the illustrated written test cannot establish it.

Implementation fidelity is a central methodological issue. A nominally identical simulation can be used as passive demonstration, unstructured exploration, or guided investigation. The present model specifies the latter and requires records of prompts, time on task, feedback, and physical comparison. Unequal internet access, additional practice, or teacher support could create differences unrelated to the intended model. Recording these conditions would allow a later study to distinguish failure of delivery from limitations of the instructional design. Cost, workload, and accessibility should be measured locally instead of assuming that virtual laboratories are cheaper or equally usable for all students.

The synthetic calculations show how baseline differences, gain scores, effect sizes, and uncertainty can be reported coherently. They do not constitute a pedagogical experiment. An advantage was explicitly specified when generating posttest scores, so its recovery by statistical analysis is expected. The numerical section should therefore be replaced with analyses of authentic, ethically collected observations before this manuscript is presented as an empirical intervention report. Published laboratory-learning evidence provides context for the design [2-4,7], but cannot supply missing outcomes for these proposed groups.

The planned nonrandomized design also has substantive limitations beyond the absence of real data. Selection, differences between classes, instructor expectations, and short-term testing effects could bias an observed contrast. Two intact classes cannot separate class-specific influences from the

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intervention. A stronger evaluation would include multiple independently allocated classes, blinded scoring where feasible, a prespecified analysis plan, and delayed and apparatus-based assessments. Actual sample-size planning should use a meaningful educational difference, plausible variability, and any clustering, rather than the effect size generated for this illustration. Until such evidence is available, conclusions should remain about the model's structure and evaluability, not its proven effectiveness.

CONCLUSION

A didactic model for using virtual laboratories in biological physics teaching is proposed as an integrated system of objectives, conceptual content, digital resources, inquiry actions, assessment-feedback processes, and organizational support. Its practical specification includes six laboratory modules, a 90-minute lesson sequence, a five-criterion assessment rubric, and checkable implementation conditions. The defining requirement is that students connect a physical relationship to experimental evidence and biological meaning while recognizing the limits of the simulated model. For the requested experimental group of 30 students and control group of 25 students, the article specifies a prospective evaluation and demonstrates analysis using explicitly synthetic records. The numerical differences are not observed learning gains and do not verify the model. Authentic implementation should combine accessible and scientifically reviewed resources, trained teachers, consistent assessment, protected data, and physical laboratory practice. The next evidential step is a transparent classroom evaluation capable of testing whether this coordinated design improves conceptual understanding, experimental reasoning, and transfer to physical tasks.

REFERENCES

1. O‘zbekiston Respublikasi Prezidenti Qarori PQ–4884. “Raqamli O‘zbekiston – 2030” strategiyasini amalga oshirish chora-tadbirlari to‘g‘risida, 2020-yil.
2. Rustamov M. USE OF MODERN METHODS IN TEACHING “INFORMATION TECHNOLOGY” IN MEDICAL EDUCATION //Science and innovation. – 2023. – T. 2. – №. A7. – C. 30-33.
3. Rustamov M. IMPROVING THE METHODOLOGY OF TEACHING THE SUBJECT “INFORMATION TECHNOLOGIES AND MODELING OF TECHNOLOGICAL PROCESSES” IN AN INNOVATIVE EDUCATIONAL ENVIRONMENT //Science and innovation. – 2023. – T. 2. – №. B7. – C. 58-61.
4. Rustamov M. Rustamov Murodil Makhammadzhanov TEACHING COMPUTER SCIENCE IN HIGHER EDUCATION: PROBLEMS AND SOLUTIONS: The rapid development of information and communication technologies in our country is due to state support, which allows us to confidently enter the world information community //Архив исследований. – 2020. – C. 5-5.
5. Rustamov M. ENHANCE STUDENTS'KNOWLEDGE AND SKILLS WITH MULTIMEDIA TOOLS IN AN INNOVATIVE EDUCATIONAL ENVIRONMENT //Science and innovation. – 2023. – T. 2. – №. B10. – C. 43-45.

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webofjournals.com/index.php/5

6. RUSTAMOV M. TIBBIY TA'LIMDA INNOVATSION TA'LIM METODLARI VA TA'LIM VOSITALARIDAN FOYDALANISHNING AFZALLIKLARI (AXBOROT TEXNOLOGIYALARI VA JARAYONLARNI MATEMATIK MODELLASHTIRISH FANIGA TADBIQI MISOLIDA) //News of the NUUz. – 2024. – T. 1. – №. 1.5. 1. – C. 197-199.
7. Tusmatov T., Gulomov S. Scientific and Methodological Foundations for Establishing a Virtual Clinical Engineering Laboratory. Society and Innovations. 2026;7(6/S):185-191. doi:10.47689/2181-1415-vol7-iss6/S-pp185-191.

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