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DIDACTIC-METHODOLOGICAL FOUNDATIONS OF IMPLEMENTING INTERNATIONAL REQUIREMENTS FOR EDUCATION QUALITY ASSESSMENT IN NATIONAL PHYSICS EDUCATION

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Abstract

This article analyzes the didactic and methodological foundations for implementing international requirements for education quality assessment in national physics education. The study is based on a design-oriented analysis of PISA and TIMSS science-assessment frameworks, national regulatory documents, and contemporary research on scientific literacy, inquiry, textbooks, STEM readiness, and digital resources. The research aim is to clarify how international assessment requirements can be transformed from external testing criteria into internal didactic indicators for physics curriculum content, textbooks, laboratory activities, digital learning resources, and assessment rubrics. The methodology relies on document analysis, comparative didactic mapping, and construction of an implementation chain: international requirement - physics content - learning activity - evidence source - assessment criterion - reflection. The results present a projection matrix that connects PISA and TIMSS requirements with concrete physics-learning tasks, including contextual problems, graph-and-table analysis, inquiry-based laboratory work, energy and environmental tasks, model limitation questions, and reflective self-assessment. The discussion shows that international requirements should not be copied mechanically into national textbooks; they should be adapted to the national curriculum, school laboratory conditions, teachers' methodological readiness, and learners' local context. The article concludes that a coherent, context-based, inquiry-oriented, digital, and reflective model of physics textbooks and teaching can strengthen students' scientific reasoning and prepare them for evidence-based decision making.

Keywords: International assessment; PISA; TIMSS; scientific literacy; national physics education; physics textbook; graph-and-table tasks; inquiry laboratory; digital resources; assessment criteria

Introduction

Education quality assessment in the modern school cannot be reduced to external control or to the measurement of final learning outcomes. International assessment programs have become important didactic benchmarks because they encourage the reconsideration of curricula, textbooks, tasks, teaching methods, laboratory work, and assessment criteria. In science education, this change is especially visible: learners are expected not only to remember facts, but also to explain phenomena, use scientific evidence, evaluate inquiry, interpret data, and justify decisions in real-life contexts [1; 2].

This requirement is particularly relevant for physics. Physics teaches learners to describe natural phenomena quantitatively, test ideas through experiments, construct models, work with graphs and tables, understand technical systems, and evaluate ecological or energy-related problems on a scientific basis. Therefore, national physics education should help learners move from the reproduction of formulas to the reasoned use of physical concepts in personal, local, national, and global contexts [2; 5].

The national physics curriculum has to respond to international assessment requirements in two interrelated directions. The first direction is content adaptation: basic physical concepts, laws, models, and phenomena must be selected and sequenced according to students' age, cognitive readiness, and life experience. The second direction is activity adaptation: questions and problems in textbooks should require learners to explain a situation, plan an experiment, analyze measurement results, derive evidence from a graph or table, and defend a conclusion. Only the combination of these two directions can transform a physics textbook into a didactic tool for developing scientific literacy.

The scientific position of this article is that PISA and TIMSS requirements should not be transferred mechanically into national physics education. They should be

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harmonized with state educational standards, school practice, laboratory facilities, textbook content, teacher methodological preparation, and the local learning context of students. Otherwise, PISA- or TIMSS-type tasks remain only external samples and cannot deeply change learners' scientific activity.

The purpose of this article is to identify the didactic-methodological foundations for implementing international education quality assessment requirements in national physics education and to show how these requirements can support the optimization of physics textbooks, laboratory work, digital resources, and assessment criteria.

Literature Review

The PISA framework interprets science assessment through the learner's ability to engage with science-related issues and to make evidence-based judgments. The PISA 2018 framework emphasized the use of content, procedural, and epistemic knowledge in explaining phenomena, evaluating scientific inquiry, and interpreting data [1]. The PISA 2025 framework strengthens this orientation by making science the major domain and by emphasizing the evaluation of scientific-enquiry designs, the critical interpretation of evidence, the use of scientific information for decision making, science identity, sustainability, and environmental education [2].

The TIMSS approach complements PISA because it is more closely connected with school curricula. TIMSS evaluates students' performance in mathematics and science at grade levels and organizes cognitive activity around knowing, applying, and reasoning [3; 4]. For physics education, this means that textbook tasks should not remain at the level of definition and formula use; they should also include the interpretation of tables, measurements, diagrams, experimental results, and cause-and-effect relationships.

A modern framework for K-12 science education connects disciplinary core ideas, scientific and engineering practices, and crosscutting concepts [5]. This logic is important for physics because motion, force, energy, matter, interaction, system, stability, change, cause, and model are not isolated themes. They are conceptual connectors that return throughout the course and allow students to transfer knowledge from one topic to another.

In Uzbekistan, the move toward competence-based standards and international assessment is supported by a series of normative and institutional documents. The state educational standards introduced a competence-based interpretation of learning outcomes [6]. The policy of participation in international studies such as PISA, TIMSS, and PIRLS created the need to reconsider curricula, textbooks, methodological guides, and teacher preparation [7; 8]. The decision on improving the quality of physics education further strengthened the connection between theoretical physics content, laboratory infrastructure, modern teaching methods, and practical application [9].

The national program for school education development and the decision on improving pedagogical education set the task of developing new-generation textbooks, exercise books, methodological guides, and practice-oriented teacher preparation [10; 11]. These documents indicate that the implementation of international requirements is not a single testing issue. It is a continuous system that includes textbooks, teachers, laboratories, digital resources, monitoring, and methodological support.

Research on science textbooks shows that the design of textbook texts and tasks can influence students' scientific literacy, especially when materials are readable, conceptually coherent, and connected with inquiry and interpretation of evidence [12]. Studies on STEM readiness emphasize that teacher preparedness, pedagogical knowledge, technological competence, confidence, and institutional support are decisive factors in the implementation of interdisciplinary and competence-based learning [13].

Inquiry-based approaches are also central to scientific literacy. A systematic review of open inquiry in science education shows positive effects on conceptual understanding, motivation, attitudes toward science, scientific and thinking skills, and science literacy; however, it also warns that inquiry requires classroom management, flexible design, and teacher support [14]. Digital resources and mobile technologies may support physics learning, but their effect depends on how they are linked with tasks, evidence, feedback, and reflection [15]. Recent analysis of the PISA 2018 and 2025 science frameworks also confirms that physics education must pay more attention to decision making, procedural and epistemic knowledge, and the interpretation of scientific information [16].

Methodology and Research Design

Research design: This article is a theoretical and design-oriented study. It does not present the results of a completed pedagogical experiment. Instead, it develops a didactic-methodological model for adapting international education quality assessment requirements to national physics education on the basis of PISA, TIMSS, national regulatory documents, and recent research on scientific literacy.

Research question: The main research question is: how can international assessment requirements be transformed into didactic and methodological indicators for national physics textbooks, laboratory activities, digital resources, and assessment rubrics?

Analytical procedure: The analysis was carried out in four steps. First, the key requirements of PISA and TIMSS were grouped into didactic categories: explanation of phenomena, inquiry design, interpretation of evidence, cognitive levels, contextualization, procedural knowledge, and epistemic knowledge. Second, the content of the school physics course was grouped around mechanics, pressure, heat, electricity, light, energy, laboratory work, environmental issues, and technical applications. Third, national educational policy documents were analyzed in terms of competence-based standards, school education development, physics education quality, and teacher training. Fourth, the international requirements and national physics content were connected through learning tasks and assessment indicators.

Design criterion: The main design criterion was professional and didactic usefulness. An international requirement was included in the projection matrix only if it could be transformed into a concrete physics-learning task. For example, the requirement to interpret data was connected with graph-and-table tasks; the requirement to evaluate inquiry was connected with laboratory variables, measurement error, and reliability; the requirement to use science for decision making was connected with energy saving, ecological safety, and technological efficiency.

Digital-didactic orientation: Digital resources were treated not as independent innovations, but as tools for strengthening physical reasoning. A simulation, virtual laboratory, video experiment, or mobile application becomes didactically meaningful only when learners change a parameter, collect evidence, compare results, construct a graph, explain a physical relation, and reflect on the reliability of the result.

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Research Results

The first result of the analysis is the clarification of an implementation chain. It begins with an international assessment requirement and continues through a physics topic, a learning activity, an evidence source, an assessment criterion, and reflection. This chain makes it possible to convert general assessment language into practical classroom and textbook design.

For example, the requirement to explain phenomena scientifically can be implemented through contextual tasks on pressure, motion, electricity, heat transfer, optical phenomena, or energy transformation. The requirement to evaluate inquiry can be implemented through laboratory tasks where learners formulate a hypothesis, identify variables, select measurement instruments, evaluate error, and write a conclusion. The requirement to interpret data can be implemented through graph-and-table tasks that ask learners to compare, extrapolate, and justify their answers.

Table 1 Projection of international assessment requirements into national physics education

International assessment requirement	Physics-education interpretation	Implementation in textbook and lesson design	Assessment evidence
Explain phenomena scientifically	Use concepts, laws, models, and cause-and-effect relations to explain natural and technical processes.	Contextual tasks on motion, pressure, heat, electricity, light, energy, and household or local technologies.	The learner explains the phenomenon and justifies the relation between cause and result.
Evaluate inquiry and interpret evidence.	Understand hypothesis, variables, measurement, error, reliability, and validity of conclusions.	Laboratory tasks with partially independent planning, variable selection, graph construction, and error discussion.	Learner identifies variables, analyzes measurement data, and evaluates the reliability of the conclusion.
Analyze data from graphs and tables.	Extract evidence from multiple representations and connect it with a physical concept.	Graph-table problems, diagrams, comparison tasks, and multi-source questions in each major topic.	Learner reads data correctly, recognizes a trend, and supports the answer with evidence.
Knowing - applying - reasoning	Balance factual knowledge, practical application, and logical justification.	Three-level task sequence: basic question, applied problem, evidence-based explanation.	Learner progresses from reproduction to application and reasoned argumentation.
Contextualization	Connect physics with personal, local, national, and global problems.	Tasks on energy saving, transport safety, water resources, Aral Sea ecology, solar energy, and household devices.	The learner makes a physics-based decision in a real-life situation.
Procedural and epistemic knowledge	Understand how scientific knowledge is produced, checked, and limited.	Questions about model assumptions, limitations, alternative explanations, history of experiments, and data reliability.	Learner reflects on model limits, possible errors, and the strength of evidence.

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The second result is the identification of five didactic indicators for optimizing physics textbooks. The first indicator is content accuracy: concepts, laws, and models must be scientifically correct, age-appropriate, and connected with later topics. The second indicator is contextualization: each topic should include personal, local, or global situations in which physics becomes a tool for analysis. The third indicator is evidence orientation: tasks should include graphs, tables, diagrams, measurement data, text fragments, or experimental conditions. The fourth indicator is inquiry orientation: laboratory work should not be limited to following a ready instruction, but should include hypothesis, variables, error, and an independent conclusion. The fifth indicator is reflection: learners should evaluate their answers, evidence, and possible mistakes.

The third result is a system of recommended task types. These include contextual qualitative questions, graph-and-table tasks, PISA-type integrated problems, TIMSS-style cognitive-level tasks, laboratory design tasks, digital simulation analysis, energy and environmental decision-making tasks, and reflective self-assessment questions. Each task type develops not only knowledge of physics, but also the ability to use evidence and justify a conclusion.

The fourth result is the clarification of a methodological contradiction. National physics textbooks often present strong content knowledge, but procedural and epistemic knowledge may appear less systematic. If a textbook contains definitions and formulas without questions about evidence, variables, model limitations, or real-life decisions, the learner may know the law but fail to use it in a new situation. Therefore, textbook optimization should include not only more tasks, but also a different structure of tasks.

Discussion

The results show that international assessment requirements can function as didactic indicators for national physics education. They help reveal gaps between the traditional textbook structure and the skills required for scientific literacy. A textbook that follows only the sequence concept - formula - example - numerical problem may develop computational skills, but it may not fully develop the ability to interpret evidence, evaluate inquiry, or justify a decision.

The proposed model also shows that PISA and TIMSS should be used together. TIMSS helps analyze the coherence of the school curriculum and the balance between knowing, applying, and reasoning. PISA helps evaluate whether the acquired knowledge can be used in real-life, social, technological, and environmental contexts. For national physics education, these two approaches are complementary: TIMSS strengthens curriculum coherence, while PISA strengthens contextual application and scientific decision making.

At the same time, adaptation must be sensitive to national conditions. International assessment tasks should not be copied into textbooks as isolated test samples. They must be reconstructed in relation to national state standards, local context, available laboratory equipment, digital infrastructure, teachers' methodological readiness, and learners' cognitive development. For example, a task on energy efficiency becomes more meaningful when it is connected with household devices, solar energy, electricity consumption, or local climatic conditions.

The role of the teacher is decisive. A PISA-type or inquiry-based task cannot work effectively if the teacher does not understand its didactic purpose, cognitive level, expected evidence, rubric, time distribution, and group-work format. Therefore, textbook optimization must be accompanied by methodological guides, professional development, examples of rubrics, and digital resources that help teachers organize evidence-based physics learning.

Digital resources require similar caution. A PhET simulation, virtual laboratory, or mobile application is not automatically a source of scientific literacy. It becomes effective when it is integrated into a task chain: question - parameter - observation - measurement - table - graph - explanation - conclusion - reflection. Without this chain, digital technology may remain only a visual demonstration.

A limitation of the present article is that it develops a theoretical and design-oriented model rather than reporting empirical data from a completed pedagogical experiment. The next stage of research should involve diagnostic tests, implementation in experimental and control groups, analysis of textbook tasks by cognitive level, and mathematical-statistical evaluation of students' progress in scientific literacy.

Conclusion

International requirements for education quality assessment are not merely external ranking tools for national education systems. For national physics education, they can serve as scientific and methodological criteria for improving

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textbook content, learning tasks, laboratory activities, digital resources, and assessment culture.

The didactic-methodological foundation proposed in this article is based on the chain: international requirement - physics topic - learning activity - evidence source - assessment criterion - reflection. This chain allows physics teaching to move from the reproduction of theoretical knowledge toward the practical use of concepts, laws, models, data, and evidence in real situations.

The main practical recommendation is to enrich physics textbooks with contextual, inquiry-based, graph-and-table, differentiated, digital, and reflective tasks. Laboratory work should be redesigned to develop procedural and epistemic knowledge, while assessment should measure not only the final answer but also the learners' evidence, reasoning, explanation, and conclusion. Such an approach can strengthen students' scientific literacy and prepare them for responsible decision-making in technological, ecological, and social contexts.

Future research should test the proposed model in real school practice, compare the results of experimental and control groups, and identify how textbook optimization, teacher methodology, and digital resources jointly influence learners' physics competence and scientific reasoning.

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