

CONTENT, CRITERIA AND PEDAGOGICAL CONDITIONS FOR DEVELOPING COMPETENCIES IN PHYSICS EDUCATION

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Abstract

The development of learners' competencies has become a central objective of contemporary education, particularly in science education, where students are expected not only to acquire conceptual knowledge but also to apply it to authentic problems and unfamiliar contexts. This article examines the content, assessment criteria, and pedagogical conditions for developing competencies in physics education. The study conceptualizes physics competence as an integrative educational outcome that combines subject knowledge, procedural skills, research abilities, data interpretation, digital literacy, communication, and reflective capacity.

Keywords: Physics education, competency-based education, physics competence, scientific literacy, competency assessment, inquiry-based learning, pedagogical conditions, digital competence, research competence, physics teaching.

Introduction

Contemporary education is increasingly concerned with what learners are able to do with knowledge rather than with the amount of information they can reproduce. Rapid technological development, digital transformation, environmental challenges, and changing labour-market requirements have increased the importance of transferable competencies that enable individuals to analyse information, solve problems, conduct investigations, communicate evidence-based conclusions, and make informed decisions.

The OECD Learning Compass 2030 conceptualizes future-oriented education through a combination of knowledge, skills, attitudes, and values and emphasizes learners' ability to navigate unfamiliar contexts rather than merely follow predetermined instructions. This orientation is particularly relevant to science education.

Physics occupies a distinctive position within science education because its learning process combines conceptual understanding with mathematical reasoning, experimentation, measurement, modelling, interpretation of empirical evidence, and technological application. Consequently, physics education provides substantial opportunities for developing integrated competencies.

The contemporary international understanding of scientific competence goes beyond the acquisition of factual knowledge. The OECD science framework emphasizes three major competency dimensions: explaining phenomena scientifically, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically. The PISA 2025 framework further emphasizes the interaction of content, procedural, and epistemic knowledge when learners apply scientific understanding to real-world contexts.

Therefore, the development of competencies in physics education requires a systematic reconsideration of the content of instruction, criteria for assessing learning outcomes, and pedagogical conditions that support students' active engagement in scientific and practical activities.

The purpose of this study is to substantiate the content, criteria, and pedagogical conditions for developing competencies in physics education.

The research objectives are:

1. to clarify the structure and content of competencies developed through physics education;
2. to identify criteria and indicators for assessing students' physics competencies;
3. to establish performance levels of competency development;
4. to determine pedagogical conditions that support competency development;
5. to develop a conceptual framework linking physics content, learning activities, assessment, and competency outcomes.

2. Literature Review

Competency-oriented education has been examined from different theoretical perspectives. Contemporary educational frameworks generally interpret competence as an integrative construct involving knowledge, skills, attitudes, values, and the ability to mobilize these resources in specific contexts.

The OECD Learning Compass 2030 identifies knowledge, skills, attitudes, and values as interconnected dimensions of competencies and places particular emphasis on students' agency in unfamiliar situations.

Within science education, the competency-oriented perspective has been particularly influential. The OECD PISA science framework defines scientific literacy through the ability to engage with scientific issues and use scientific knowledge in meaningful contexts. Its competency dimensions include scientific explanation, scientific enquiry, and interpretation of scientific data and evidence.

The PISA framework also distinguishes among three forms of scientific knowledge:

- **content knowledge** — knowledge of scientific concepts, facts, and theories;
- **procedural knowledge** — understanding of scientific procedures and practices;
- **epistemic knowledge** — understanding of how scientific knowledge is justified and established.

These three dimensions are particularly relevant to physics because meaningful physics learning requires students to understand physical concepts, conduct experiments, analyse measurements, and evaluate the reliability of evidence.

Traditional physics instruction has often been dominated by conceptual explanations, formula application, and reproductive problem solving. While these elements remain necessary, they do not by themselves demonstrate whether learners can transfer their knowledge to unfamiliar situations.

A competency-oriented model therefore requires a broader learning outcome in which students can:

understand → apply → investigate → analyse → evaluate → communicate → reflect.

This conceptual shift provides the theoretical basis for the present study.

3. Materials and Methods

The study employed a theoretical research design based on the analysis and synthesis of contemporary educational frameworks and pedagogical literature.

The following methods were applied:

- theoretical analysis of competency-based education;
- comparative analysis of international science education frameworks;
- content analysis of competency definitions;
- pedagogical modelling;

- systematization and classification;
- analysis of assessment criteria;
- synthesis of pedagogical conditions.

The OECD science frameworks were used as an international reference point for identifying major dimensions of scientific competence.

The proposed structure of physics competence was developed by adapting these general scientific competencies to the specific epistemological and methodological characteristics of physics.

4. Results

4.1. The Content Structure of Competencies in Physics Education. Physics competence should not be reduced to the ability to recall physical laws or solve standard numerical exercises. It should be understood as an integrated capacity to mobilize physics knowledge, practical skills, scientific reasoning, research procedures, digital tools, and communication resources to solve problems in different contexts.

Based on the theoretical analysis, seven interrelated components of physics competence can be identified.

Table 1. Structural Components of Physics Competence

Component	Core content	Expected learner performance
Cognitive	Concepts, laws, theories and principles of physics	Explains physical phenomena
Practical	Application of physics knowledge	Solves authentic practical problems
Research	Inquiry, experimentation and hypothesis testing	Designs and conducts investigations
Data-analytical	Measurement, calculation and interpretation	Analyses experimental data
Digital	Simulation, modelling and digital tools	Uses digital technologies for physics learning
Communicative	Scientific argumentation and presentation	Communicates evidence-based conclusions
Reflective	Self-assessment and evaluation	Evaluates learning and problem-solving processes

These components are not independent. They interact during authentic physics activities.

For example, when investigating the relationship between voltage and current, a learner must understand the relevant physical concepts, formulate a hypothesis, select appropriate equipment, collect data, represent the results graphically, interpret the relationship, evaluate possible errors, and communicate the conclusion.

Therefore, competence emerges through the **integration of knowledge and action** rather than through isolated acquisition of individual skills.

4.2. Cognitive and Subject-Specific Competence. The cognitive component represents the conceptual foundation of physics competence.

Students need to understand:

- physical quantities and units;
- fundamental laws and principles;
- mathematical relationships;
- physical models;
- causal relationships;
- mechanisms underlying natural phenomena.

However, conceptual understanding should be demonstrated through application.

For example, knowledge of Newton's laws should enable students not only to reproduce their definitions but also to explain motion in authentic situations, construct appropriate models, identify forces, and justify predictions.

Thus, the cognitive component can be described as:

conceptual knowledge + causal reasoning + model construction + application.

4.3. Practical and Problem-Solving Competence. The practical component reflects the learner's ability to transfer theoretical knowledge into practical situations.

Practice-oriented physics tasks may include:

- calculating energy consumption;
- analysing mechanical systems;
- determining thermal efficiency;
- investigating electrical circuits;
- evaluating measurement accuracy;
- analysing the efficiency of technological devices.

Such tasks should contain contextual information and may require learners to select appropriate physical principles rather than simply apply a previously demonstrated algorithm.

The transition can therefore be represented as:

routine task → contextual task → unfamiliar problem → independent solution.

This progression enables learners to move from procedural performance toward flexible application.

5. Research and Experimental Competence. Physics is fundamentally connected with empirical investigation. Consequently, research competence is one of the central components of physics education. Research competence includes the ability to:

1. identify a researchable question;
2. formulate a hypothesis;
3. identify variables;
4. design an investigation;
5. select appropriate instruments;
6. conduct measurements;
7. record and process data;
8. identify uncertainty and possible sources of error;
9. interpret results;
10. formulate evidence-based conclusions.

The OECD science framework similarly emphasizes the ability to evaluate and design scientific enquiry and to interpret scientific data and evidence.

Consequently, laboratory activities should not be limited to following predetermined instructions. Where pedagogically appropriate, learners should be given opportunities to make decisions about experimental design.

6. Data-Analytical and Digital Competence. Modern physics education increasingly requires students to work with quantitative and digital information. Students should be able to:

- read tables and graphs;
- construct graphical representations;
- identify relationships between variables;
- calculate averages and rates;

- recognize measurement uncertainty;
- interpret patterns;
- distinguish correlation from causal explanation where relevant;
- use digital tools for data analysis.

Digital competence adds another dimension to this process.

Digital simulations can allow students to manipulate parameters, visualize invisible processes, compare theoretical predictions with observations, and investigate situations that may be difficult to reproduce experimentally.

However, digital tools should support conceptual and experimental learning rather than replace scientific reasoning.

The pedagogical principle can therefore be formulated as:

technology as a means of inquiry, not technology as an end in itself.

7. Criteria and Indicators for Assessing Physics Competencies. Competency-based assessment requires observable criteria and indicators.

Based on the proposed structure, five major assessment criteria can be identified.

Table 2. Criteria and Indicators of Physics Competence

Criterion	Indicators
Cognitive	Accuracy of concepts, understanding of laws, ability to explain phenomena
Activity-based	Ability to apply knowledge and select appropriate solution strategies
Research	Formulation of hypotheses, experimental planning, data collection and interpretation
Communicative	Scientific argumentation, presentation and justification of conclusions
Reflective	Self-evaluation, identification of errors, improvement of strategies

These criteria should be interpreted as interconnected dimensions rather than isolated assessment categories.

For example, a student who correctly calculates a result but cannot explain its physical meaning demonstrates partial achievement. Competent performance requires conceptual interpretation, appropriate procedure, evidence-based reasoning, and communication.

8. Levels of Competency Development. For practical assessment, three levels can be proposed: **basic, functional, and advanced.**

Basic level

The learner:

- recognizes basic physical concepts;
- reproduces known laws;
- solves standard problems with assistance;
- follows established experimental procedures.

Functional level

The learner:

- applies physical knowledge to familiar contexts;
- selects appropriate formulas or principles;
- conducts routine investigations;
- interprets tables and graphs;
- explains results with limited assistance.

Advanced level

The learner:

- applies knowledge to unfamiliar contexts;
- independently designs investigations;
- evaluates evidence critically;
- identifies limitations and uncertainties;
- integrates digital and mathematical tools;
- proposes alternative solutions;
- communicates evidence-based conclusions independently.

This three-level framework can be adapted to diagnostic, formative, and summative assessment.

9. Pedagogical Conditions for Developing Competencies. The development of competencies requires a coordinated system of pedagogical conditions.

9.1. Practice-Oriented Content. Physics concepts should be connected with authentic situations, technological applications, professional contexts, and everyday phenomena.

The contextualization of physics makes abstract concepts meaningful and increases opportunities for transfer.

9.2. Inquiry-Based Learning. Students should have opportunities to formulate questions, develop hypotheses, design experiments, and interpret evidence.

Inquiry-based learning creates a direct relationship between scientific knowledge and scientific practice.

9.3. Problem-Based Learning. Problem situations should require students to identify relevant information, select appropriate principles, construct models, and justify solutions. This supports higher-order thinking and transfer.

9.4. Experimental and Laboratory Activities. Laboratory work should move beyond confirmation of previously taught laws toward investigation, measurement, analysis, and explanation.

9.5. Digital Modelling and Simulation. Digital tools can provide opportunities to visualize complex processes, manipulate variables, and analyse data. Their pedagogical use should be integrated with conceptual understanding and experimental reasoning.

9.6. Interdisciplinary Integration. Physics should be connected with mathematics, computer science, engineering, environmental studies, and professional disciplines. Such integration supports the transfer of knowledge across contexts.

9.7. Reflective Learning. Students should regularly evaluate:

- what they have learned;
- how they solved a problem;
- which strategies were effective;
- what errors occurred;
- how the solution could be improved.

Reflection transforms individual learning experiences into transferable learning strategies.

9.8. Competency-Oriented Assessment. Assessment should include authentic tasks that require learners to demonstrate application, investigation, interpretation, and communication.

The OECD framework emphasizes that scientific competence involves the ability to use knowledge and evidence in meaningful contexts rather than merely reproduce scientific information.

10. A Conceptual Model for Competency Development in Physics Education. The model demonstrates that competencies are not produced by content alone. They emerge through the interaction of content, activity, context, assessment, and reflection.

11. Discussion. The findings support the view that competency development in physics requires a transition from content-centred instruction toward an integrated learning system.

The international science education frameworks provide an important conceptual foundation for this transition. The OECD PISA framework identifies scientific explanation, scientific enquiry, and interpretation of data and evidence as central competencies. The PISA 2025 framework further emphasizes the combination of content, procedural, and epistemic knowledge.

For physics education, these principles can be operationalized through authentic problem solving, laboratory research, modelling, data analysis, and digital learning.

An important implication is that competency development should not be treated as an additional component added to the curriculum. Instead, competencies should be embedded within the learning objectives, content, instructional activities, and assessment system.

The role of the teacher also changes. The teacher becomes not only a transmitter of information but also a designer of learning environments, facilitator of inquiry, provider of feedback, and organizer of reflective activities. The OECD Teaching Compass similarly emphasizes teachers' professional competencies and agency in implementing future-oriented learning.

12. Conclusion. The study demonstrates that competency development in physics education should be understood as a multidimensional educational process that integrates conceptual knowledge, practical application, scientific inquiry, data analysis, digital tools, communication, and reflection.

The proposed framework identifies seven interconnected components of physics competence: cognitive, practical, research, data-analytical, digital, communicative, and reflective.

Five major assessment criteria are proposed: cognitive, activity-based, research, communicative, and reflective. These criteria can be operationalized through observable indicators and three developmental levels: basic, functional, and advanced.

The analysis indicates that the development of competencies depends on a system of pedagogical conditions, including practice-oriented content, inquiry-based learning, problem-based tasks, laboratory research, digital modelling, interdisciplinary integration, reflective learning, and competency-oriented assessment.

The central pedagogical implication is that physics education should provide learners with systematic opportunities to **use knowledge**, rather than merely acquire and reproduce it. Such an approach is consistent with contemporary international science education frameworks, which emphasize the application of scientific knowledge, investigation, evidence interpretation, and informed decision-making.

Further empirical research should investigate the effectiveness of the proposed criteria and pedagogical conditions through experimental studies involving control and experimental groups, validated competency assessment instruments, and quantitative analysis of learning outcomes.

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