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PEDAGOGICAL MECHANISMS FOR DEVELOPING PRACTICAL COMPETENCE IN PHYSICS EDUCATION THROUGH OUTCOME-ORIENTED COMPETENCY-BASED ASSESSMENT

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Abstract

This article substantiates the pedagogical mechanisms for developing students' practical competence in physics education through outcome-oriented competency-based assessment. The central argument is that assessment in a technical university should not be reduced to the registration of final marks or the reproduction of theoretical definitions. It should function as a developmental pedagogical system that connects learning outcomes, professional content, student activity, authentic tasks, criteria, evidence, feedback, feedforward and reflective self-regulation. The article interprets practical competence as an integrative quality that includes conceptual understanding, experimental reasoning, mathematical modelling, technological interpretation, evidence-based decision-making and reflective responsibility. In physics education, such competence becomes visible when a student can transfer a physical law to a professional-practical situation, transform a technical problem into a physical model, collect and interpret experimental data, justify a solution and critically evaluate the reliability of the obtained result. The paper proposes a model of outcome-oriented competency-based assessment, a criterion-indicator matrix, a methodological algorithm for designing physics lessons and a set of pedagogical mechanisms aimed at aligning the goal, content, activity and assessment of the learning process. Special attention is paid to authentic engineering-oriented tasks, rubrics, formative feedback, feedforward, peer interaction, self-assessment and digital monitoring tools. The suggested approach contributes to the improvement of physics teaching in technical higher education by shifting the focus from knowledge reproduction to the demonstrable ability to apply knowledge in meaningful professional contexts.

Keywords: Outcome-oriented education; competency-based assessment; practical competence; physics education; authentic task; assessment rubric; formative feedback; feedforward; reflective learning; professional-practical situation; learning outcomes; constructive alignment.

Introduction

In contemporary higher education, physics is no longer viewed merely as a set of theoretical laws and formulas to be transmitted to students. In technical universities, physics performs a broader professional and methodological function: it develops engineering thinking, modelling culture, experimental literacy, analytical reasoning and the ability to make justified decisions in uncertain technical situations. Therefore, the quality of physics education must be evaluated not only by the amount of material covered during a course, but also by the degree to which students can use physical knowledge as an instrument for solving professional and practical problems.

This shift has changed the meaning of assessment. Traditional assessment often focuses on tests, oral answers and final examinations that primarily reveal what a student remembers. Such forms are useful, but they do not fully show whether the student can apply a concept in a real situation, interpret measurement results, identify sources of error, choose an appropriate model or explain the technological significance of a physical phenomenon. For future engineers, these abilities are essential, because professional activity requires not only knowledge, but also the capacity to mobilize knowledge in action.

Outcome-oriented competency-based assessment responds to this need by linking expected learning outcomes with learning activities and evidence of performance. It requires the teacher to define what the student should be able to do at the end of a lesson, laboratory work or module; to design tasks that make this activity visible; to establish transparent criteria and indicators; and to provide feedback that helps the student improve the next step of learning. In this sense, assessment becomes an internal mechanism of teaching rather than an external procedure that follows teaching.

The aim of this article is to provide a scientific and methodological justification for the pedagogical mechanisms through which outcome-oriented competency-based assessment can develop students' practical competence in physics education. To achieve this aim, the article analyzes the conceptual basis of competency-based assessment, clarifies the structure of practical competence, proposes criteria and indicators, and describes a lesson-design mechanism that integrates authentic professional-practical tasks, formative feedback, rubrics and reflective self-assessment.

Literature Review and Theoretical Framework

The outcome-oriented approach in pedagogy is based on the idea that educational goals should be formulated as observable and assessable learning results. In this framework, a learning outcome is not a general intention of the teacher, but a clear description of the activity that a student is expected to perform. For example, in physics education, an outcome may be expressed as follows: the student analyzes the relation between voltage, current and resistance in an applied electrical circuit, presents measurement results in tables and graphs, and explains the causes of experimental error. Such wording immediately connects knowledge with action and assessment.

A closely related principle is constructive alignment. It requires coherence among learning outcomes, teaching methods, learning tasks and assessment tools. If the declared learning outcome is the ability to solve a professional-practical problem, then the assessment cannot be limited to a reproductive test. It should include tasks that require modelling, experimentation, interpretation and justification. In physics education, constructive alignment allows the teacher to transform a lesson into a logically connected didactic system in which the concept, experiment, calculation and reflection work together.

Competency-based assessment is also grounded in criterion-referenced evaluation. In this approach, a student's achievement is judged not by comparison with other students, but by comparison with predetermined criteria, indicators and descriptors. The criteria make assessment transparent, while descriptors clarify what counts as high, sufficient or initial performance. In physics, such criteria may include the correct interpretation of a physical law, the selection of an appropriate formula or model, the accuracy of measurement, the construction of a graph, the analysis of error, the ability to connect a result with a technical situation and the capacity to formulate a reflective conclusion.

Modern didactics distinguishes three interrelated functions of assessment: assessment of learning, assessment for learning and assessment as learning. Assessment of learning summarizes achievement at the end of a unit or course. Assessment for learning supports the student during the learning process through formative feedback. Assessment as learning develops the learner's ability to evaluate his or her own progress, understand mistakes and plan further improvement. In technical physics education, these three functions should be combined in laboratory work, engineering-oriented problems, projects, simulations and case-based tasks.

Practical competence in physics is broader than the ability to reproduce theoretical information. It integrates conceptual knowledge, experimental activity, mathematical processing, modelling, technological interpretation, communication, responsibility and reflective evaluation. A student with developed practical competence can explain a physical phenomenon, select an adequate method of

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investigation, conduct measurements, process data, justify the reliability of conclusions and transfer the obtained result to an applied context. Therefore, competency-based assessment should evaluate not only the final answer, but also the reasoning pathway and the quality of the student's activity.

Research Methodology

The methodology of the study is based on outcome-oriented education, competency-based learning, activity-based instruction, authentic assessment, criterion-referenced monitoring and reflective pedagogy. These methodological foundations make it possible to design physics education as a sequence of purposeful actions: defining outcomes, selecting professional content, organizing student activity, collecting evidence, assessing performance and improving learning through feedback.

The proposed methodological algorithm includes six stages. First, the learning outcome is formulated through concrete activity verbs such as analyze, calculate, model, measure, compare, justify, predict and improve. Second, a professional-practical situation is selected in accordance with the learning outcome. Third, criteria, indicators and descriptors are defined before the task is performed. Fourth, an assessment tool is selected: laboratory work, applied problem, project, simulation, mini-case or engineering task. Fifth, formative feedback and feedforward are provided during the learning process. Sixth, the final performance is analyzed through a rubric and connected with the student's individual development trajectory.

The methodological value of this algorithm lies in the fact that it makes assessment evidence-based. The teacher does not evaluate a general impression of the student's answer; rather, he or she analyzes concrete evidence of activity: a graph, a calculation, a laboratory report, a model, an argument, a reflection note or a project solution. This approach increases objectivity and creates conditions for the gradual development of practical competence.

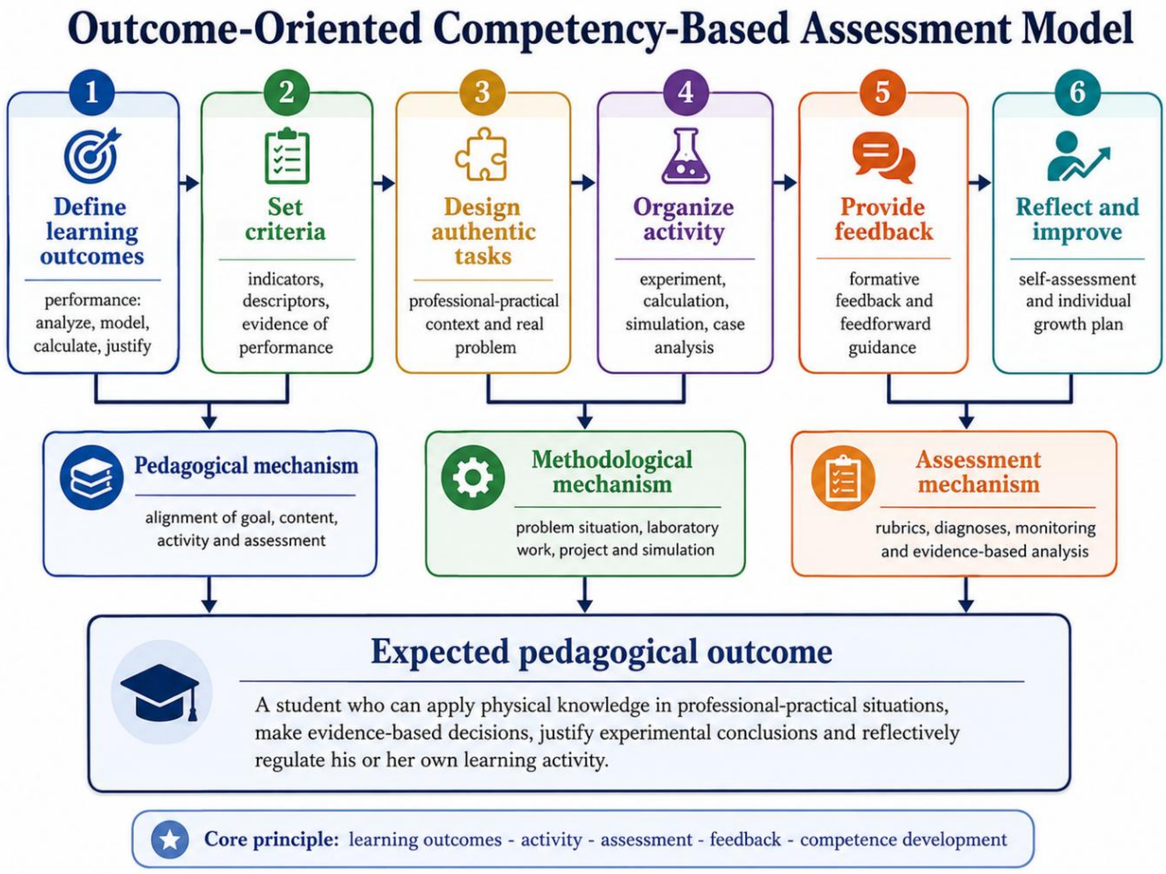

Figure 1. Model of developing practical competence through outcome-oriented competency-based assessment

Results and Analysis

The introduction of outcome-oriented competency-based assessment in physics education begins with the reformulation of the lesson objective. Instead of a general statement such as “the student knows Ohm’s law,” it is methodologically more productive to state that “the student analyzes the relationship among current, voltage and resistance in an electrical circuit, processes the measurement results, constructs a graph and explains the causes of possible error.” This formulation shows what the student should do, what evidence should be collected and how the result should be assessed.

The first pedagogical mechanism is the alignment of the learning goal and the assessment criterion. If the purpose of the lesson is to develop practical competence, the lesson structure must include activity that requires the application of knowledge. Theoretical explanation, laboratory action, calculation, modelling, interpretation and reflection should not be separated into isolated fragments; they should be organized as one didactic chain. Such alignment prevents the situation in which students memorize formulas but cannot use them in professional contexts.

The second mechanism is the design of authentic professional-practical tasks. An authentic task reflects a real or realistic engineering situation. For instance, in a lesson on heat transfer, the student should not only calculate a value from a formula, but also evaluate a construction material, analyze thermal insulation, consider energy efficiency and justify a technical choice. In this case, the physical law is transferred to a professional context and practical competence becomes visible through the student's activity.

The third mechanism is the use of criterion-based rubrics. A rubric helps the teacher evaluate the student's work not by subjective impression, but by predetermined indicators. In a laboratory report, for example, the rubric may include the explanation of the theoretical basis, the description of the experimental setup, the accuracy of measurement, the correctness of data processing, the construction of a graph, the identification of error sources, the connection of the result with a professional situation and the formulation of a reflective conclusion. Each indicator should have descriptors for different levels of performance.

The fourth mechanism is formative feedback and feedforward. Feedback explains the current quality of the student's work, while feedforward indicates what should be improved in the next learning action. For example, a comment such as "the calculation is wrong" is not sufficiently developmental. A more effective response is: "the final value is distorted because the units were not fully converted into the SI system; in the next task, add a separate step for checking units before substituting values into the formula." Such feedback helps the student understand the source of the error and develop a corrective learning strategy.

The fifth mechanism is reflective assessment. At the end of a laboratory or applied task, the student should not simply submit a result. He or she should analyze which stage was difficult, where an error appeared, which physical law played the decisive role, how reliable the data are and where the obtained result can be used in professional practice. Reflection transforms assessment into a tool of self-regulation and strengthens the student's independent learning strategy.

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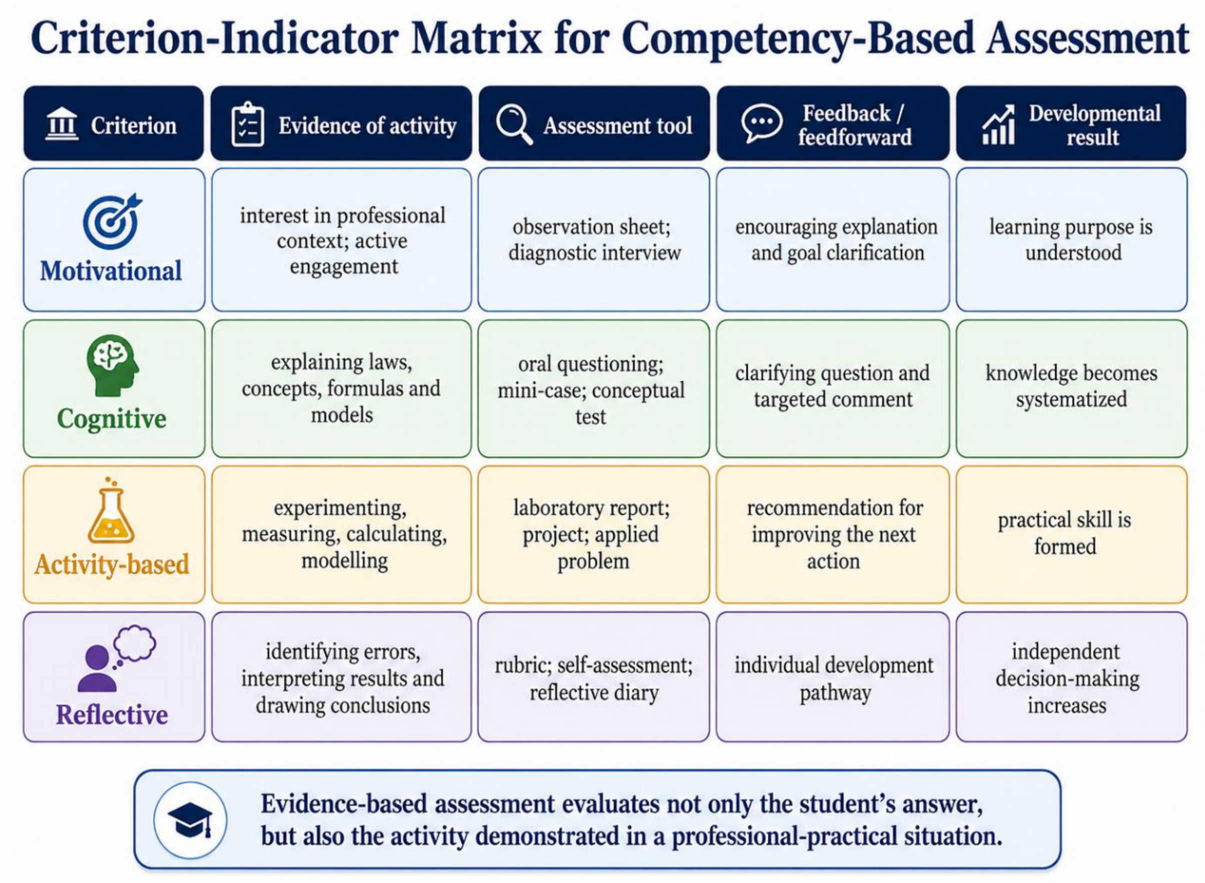

Criterion-Indicator Matrix for Competency-Based Assessment

Criterion	Evidence of activity	Assessment tool	Feedback / feedforward	Developmental result
Motivational	interest in professional context; active engagement	observation sheet; diagnostic interview	encouraging explanation and goal clarification	learning purpose is understood
Cognitive	explaining laws, concepts, formulas and models	oral questioning; mini-case; conceptual test	clarifying question and targeted comment	knowledge becomes systematized
Activity-based	experimenting, measuring, calculating, modelling	laboratory report; project; applied problem	recommendation for improving the next action	practical skill is formed
Reflective	identifying errors, interpreting results and drawing conclusions	rubric; self-assessment; reflective diary	individual development pathway	independent decision-making increases

Evidence-based assessment evaluates not only the student's answer, but also the activity demonstrated in a professional-practical situation.

Figure 2. Criterion-indicator matrix for competency-based assessment in physics education

Criteria and Indicators of Competency-Based Assessment

In outcome-oriented competency-based assessment, the level of development of practical competence can be determined through four interrelated criteria: motivational, cognitive, activity-based and reflective. These criteria should not be interpreted as separate components. They function as an integrated pedagogical system. The motivational criterion reflects professional interest and readiness for learning activity. The cognitive criterion shows the understanding of physical concepts, laws and models. The activity-based criterion reveals the ability to conduct experiments, perform calculations and construct models. The reflective criterion indicates the ability to analyze one's own result, recognize errors and define the next step of improvement.

Table 1. Criteria for assessing practical competence in physics education

Criterion	Indicators	Assessment evidence	Developmental result
Motivational	professional interest; responsibility; active involvement in a problem situation	diagnostic interview, observation sheet, motivational questions	understanding the professional value of physical knowledge
Cognitive	explaining concepts, laws, formulas and models in accordance with a situation	conceptual test, oral answer, case analysis	readiness to apply theoretical knowledge systematically
Activity-based	conducting experiments; measuring; calculating; modelling; proposing a solution	laboratory report, project, applied problem	ability to offer a justified solution in a professional-practical situation
Reflective	analyzing a result; identifying errors; drawing conclusions; planning improvement	rubric, self-assessment, reflective diary	development of an independent learning and improvement strategy

Mechanism for Designing and Conducting a Physics Lesson

The design of an outcome-oriented physics lesson begins with the precise definition of the expected learning result. The result should be expressed through an activity that can be observed and evaluated: the student analyzes, calculates, models, measures, constructs a graph, explains, compares, justifies or improves. Such verbs determine both the structure of the lesson and the form of assessment.

At the second stage, the content of the lesson is enriched with a professional context. In mechanics, concepts such as force, mass, acceleration and momentum can be related to transport, construction, mechanical engineering and energy systems. In thermodynamics, topics can be connected with heat exchange, energy-saving technologies, cooling systems and industrial devices. In electromagnetism, tasks may be designed around electrical circuits, sensors, automation, safety and diagnostic procedures. This contextualization increases the practical meaning of the physics content.

At the third stage, the assessment tool is selected according to the nature of the outcome. If the expected result is the correct application of a formula, an applied problem may be sufficient. If the result concerns the justification of experimental evidence, a laboratory report and graphical analysis are required. If the expected result is a professional decision, a project, mini-case or engineering task should be used. Thus, the assessment tool must be didactically consistent with the intended learning outcome.

At the fourth stage, formative feedback is organized during the student's activity. The teacher should not provide ready-made answers. Instead, he or she guides the student through questions, interim criteria, samples of descriptors, checklists and self-assessment sheets. Such guidance preserves student independence while reducing methodological uncertainty.

At the fifth stage, the final result is analyzed according to the criteria. The final assessment should not be limited to a numerical mark. It should be accompanied by an analytical conclusion that identifies which competence has been formed strongly, which component still needs development and what learning action should be performed in the next stage.

Discussion

Outcome-oriented competency-based assessment activates the content of physics education because it encourages students to perceive a topic not as an abstract theoretical object, but as a resource for solving a professional task. This increases learning motivation and strengthens the practical value of physics in technical higher education. It also creates conditions for the integration of knowledge, skills and personal responsibility.

At the same time, this approach requires serious methodological preparation from the teacher. For each topic, the teacher must develop an outcome, a professional context, an authentic task, indicators, a rubric and feedback tools. In a traditional lesson, the teacher mainly explains the topic. In competency-based assessment, the teacher acts as a pedagogical designer: he or she designs learning activity, observes evidence, provides feedback, guides reflection and supports individual development.

The proposed mechanism is especially effective when combined with laboratory work, applied problem solving, independent learning, project activities, virtual laboratories and digital simulations. Digital tools, electronic rubrics, learning management systems and elements of learning analytics can make assessment more transparent and convenient for monitoring. However, technology should support pedagogical logic, not replace it. The main goal remains the development of the student's ability to apply physical knowledge responsibly and creatively in professional-practical situations.

Conclusion

Outcome-oriented competency-based assessment in physics education functions as a modern pedagogical mechanism for developing practical competence. It makes it possible to evaluate the student's knowledge, activity, professional decision and reflective position as an integrated system. In this approach, assessment is not only a control tool; it becomes a developmental environment that connects the content of the lesson with professional practice and shows the student's individual growth.

The study leads to several conclusions. First, the development of practical competence in physics requires learning outcomes to be formulated through clear activity-based indicators. Second, assessment criteria should be based on motivational, cognitive, activity-based and reflective components. Third, authentic professional-practical tasks develop the ability to apply physical knowledge in real or realistic situations. Fourth, formative feedback and feedforward help students identify errors, improve reasoning and plan further development. Fifth, rubrics and reflective assessment provide a more objective way to determine the level of practical competence.

Thus, physics lessons organized through outcome-oriented competency-based assessment systematically develop future engineers' ability to transfer theoretical knowledge into professional activity, justify experimental results, choose solutions in problem situations and evaluate their own learning activity. This approach contributes to the modernization of physics education in technical universities and strengthens the connection between fundamental science, engineering thinking and professional competence.

Recommendations

- For the effective implementation of outcome-oriented competency-based assessment in physics education, each lesson and laboratory activity should begin with clearly defined learning outcomes that are linked to observable student actions.
- Physics tasks should be enriched with engineering-oriented contexts so that students can understand the professional significance of physical laws and models.
- Assessment rubrics should be developed for laboratory reports, applied problems, projects and simulations; these rubrics should include indicators for knowledge, activity, evidence, interpretation and reflection.
- Feedback should be formative and developmental: it should explain not only what is wrong, but also how the student can improve the next learning action.
- Digital tools, virtual laboratories and electronic monitoring systems should be integrated into the assessment process when they support transparency, evidence collection and individualized learning trajectories.

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