

# Methodological Foundations for Developing Students' Critical Thinking Through Formative Assessment in Physics Education

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**Abstract:** This article examines the methodological foundations for developing students' critical thinking competence through formative assessment in physics education. In contemporary education, learners are expected not merely to acquire ready-made knowledge, but also to analyse physical phenomena, identify cause-and-effect relationships, draw evidence-based conclusions, justify their opinions, and make independent decisions in problem situations. From this perspective, formative assessment is interpreted not only as a tool for evaluating final learning outcomes, but also as a pedagogical and methodological mechanism that reveals, supports, and develops the learner's thinking process.

The article analyses the significance of critical thinking in physics education, as well as the diagnostic, developmental, reflective and evidence-oriented characteristics of formative assessment. It also presents a comparative analysis of traditional and formative assessment, formative assessment tasks based on physics topics, a methodological model aimed at developing students' critical thinking, expected pedagogical outcomes, and practical recommendations for physics teachers.

**Keywords:** Formative assessment, critical thinking, physics education, feedback, reflection, argumentation, methodological model, assessment for learning, learner engagement.

**Introduction:** In the context of globalisation, digital transformation and competency-based education, the main task of education is not limited to transmitting ready-made knowledge to learners. Modern education is oriented toward developing students as individuals who can think independently, analyse information, make reasonable decisions in problem situations, justify their ideas with evidence, and apply knowledge in real-life contexts.

This task is of particular importance in teaching physics. Physics studies natural phenomena, and in this subject theoretical knowledge, experiment, observation, mathematical calculation, graphical analysis, modelling and logical interpretation are closely interconnected. A learner should not merely memorise a physical law, but should be able to apply it to a real situation, explain experimental results, draw conclusions from graphs,

and clarify the causes of phenomena.

Therefore, developing critical thinking competence is one of the essential methodological tasks of physics education. Critical thinking is the learner's ability to avoid superficial acceptance of a phenomenon, process or problem; to analyse it; to identify causes and consequences; to compare different pieces of evidence; to detect errors; and to draw justified conclusions.

Formative assessment plays an important role in this process. While traditional assessment often serves to determine a learner's final result, formative assessment makes it possible to monitor the learner's development during the learning process, identify errors, provide timely support, and guide further learning activities. For this reason, investigating formative assessment as an effective methodological

mechanism for developing critical thinking is a relevant pedagogical issue.

#### **Aim of the Study**

The aim of this article is to clarify the methodological foundations for developing students' critical thinking through formative assessment in physics education and to propose a methodological model based on the integration of formative assessment and critical thinking.

#### **Research Objectives**

To achieve this aim, the following objectives were defined:

- to analyse the theoretical significance of the concept of critical thinking in physics education;
- to identify the pedagogical and methodological characteristics of formative assessment;
- to compare the influence of traditional and formative assessment on students' thinking processes;
- to substantiate the interrelationship between formative assessment and critical thinking;
- to identify formative assessment methods that contribute to the development of critical thinking in physics lessons;
- to develop a methodological model for developing critical thinking on the basis of formative assessment;
- to formulate practical recommendations for physics teachers.

#### **Scientific Novelty**

The scientific novelty of this article lies in the fact that formative assessment in physics education is justified not merely as an assessment tool for determining students' level of mastery, but as a pedagogical and methodological mechanism for developing critical thinking. In addition, the article proposes a methodological model in which the elements of formative assessment—diagnosis, problem-based questioning, argumentation, feedback, reflection and improvement—are integrated with the components of critical thinking. This model supports the development of students' abilities to analyse, identify cause-and-effect relationships, understand mistakes, justify ideas with evidence and draw independent conclusions in physics lessons.

#### **METHODOLOGY**

The study employed theoretical-analytical, comparative-pedagogical, modelling and generalisation methods. Through the theoretical-analytical method, scientific and methodological sources related to formative assessment, critical thinking and physics education were studied. On the basis of comparative-pedagogical analysis, the influence of traditional and formative assessment on students' thinking processes was compared.

Using the modelling method, a staged methodological model for developing critical thinking through formative assessment in physics education was designed. Through generalisation, the practical possibilities, expected results and methodological recommendations for applying formative assessment in physics lessons were systematised.

#### **1. Methodological Significance of Critical Thinking in Physics Education**

Critical thinking is regarded in modern education as one of the key competencies that determines a learner's intellectual development. It includes independent reasoning, analysing evidence, viewing a problem from different perspectives, substantiating conclusions, and reconsidering one's own ideas.

The importance of critical thinking increases considerably in physics education, because understanding physical phenomena is formed not through simple memorisation but through observation, experiment, analysis, comparison, modelling and argumentation. For example, a learner may memorise the statement that "electric current depends on voltage." However, when the learner can explain how current depends on voltage and resistance according to Ohm's law, analyse a graph and interpret the situation in a real electric circuit, this indicates the formation of critical thinking skills.

In physics lessons, critical thinking manifests itself in the following situations:

- explaining the cause of a physical phenomenon;
- applying a formula or law to a real situation;
- analysing experimental results;
- drawing conclusions from graphs or tables;
- identifying an incorrect idea or mistake;
- justifying an answer with evidence;

- comparing alternative solutions;
- making an independent decision in a problem situation.

Thus, developing critical thinking in physics not only improves students' knowledge level, but also forms their scientific thinking.

## 2. The Content and Pedagogical Characteristics of Formative Assessment

Formative assessment is a type of assessment that involves continuous monitoring of students' development during the learning process, identifying gaps in their knowledge and skills, adapting instruction, and actively involving learners in their own educational activity.

The main purpose of formative assessment is not to assign a final grade to the learner, but to improve the learning process. In this respect, it is based not on the principle of "teaching for assessment," but on the principle of "assessment for learning."

Formative assessment has the following pedagogical characteristics:

First, it has a diagnostic character. Formative assessment identifies how well the learner has understood the topic, where he or she is experiencing difficulty, and what kind of support is needed.

Second, it has a developmental character. It does not

merely assess the learner's knowledge, but helps move the learner to the next level.

Third, it has a reflective character. The learner begins to understand his or her own knowledge, mistakes, achievements and development pathway.

Fourth, it ensures active participation. The learner becomes not only an object of assessment, but also a subject of it. In other words, the learner evaluates his or her own work, analyses a peer's work, and reasons on the basis of criteria.

Fifth, it is oriented toward argumentation. In formative assessment, learners are expected to provide not only an answer, but also the basis, reason and evidence behind that answer.

Therefore, formative assessment creates a favourable methodological environment for the development of critical thinking.

## 3. Comparative Analysis of Traditional and Formative Assessment

The main difference between traditional assessment and formative assessment is reflected in their goals, their influence on learner activity, and their attitude toward errors. Traditional assessment is generally aimed at determining the final result, whereas formative assessment supports the learner's development during the learning process itself.

| Criterion                      | Traditional assessment        | Formative assessment                               |
|--------------------------------|-------------------------------|----------------------------------------------------|
| Main purpose                   | Assessing the final result    | Improving the learning process                     |
| Time of assessment             | At the end of a topic or unit | Continuously during the lesson                     |
| Learner's role                 | Object being assessed         | Active participating subject                       |
| Teacher's role                 | Controller                    | Guide and supporter                                |
| Attitude toward errors         | Considered a negative result  | Considered a source of development                 |
| Feedback                       | General or limited            | Specific, guiding and developmental                |
| Influence on critical thinking | Limited                       | Strengthens analysis, argumentation and reflection |
| Outcome                        | Grade or score                | Identification of the direction for development    |

As the table shows, formative assessment turns the learner into an active participant in the assessment process. This develops the learner's ability to analyse his or her own ideas, understand mistakes, provide evidence, and manage the learning process.

#### 4. The Interrelationship between Formative Assessment and Critical Thinking

Formative assessment and critical thinking are directly related pedagogical processes. Formative assessment reveals the learner's thinking process, while critical thinking gives deeper meaning to this process.

In traditional assessment, the teacher mainly seeks an answer to the question "Is the result correct or incorrect?" In formative assessment, however, questions such as "How did the learner think?", "Where did he or she make a mistake?", "Why did the learner reach this conclusion?", and "How can the learner be moved to the next stage?" become important.

For example, when a learner is asked "What is electric current?" in a physics lesson, the question mainly checks reproductive knowledge. However, the question "Why does the current decrease when

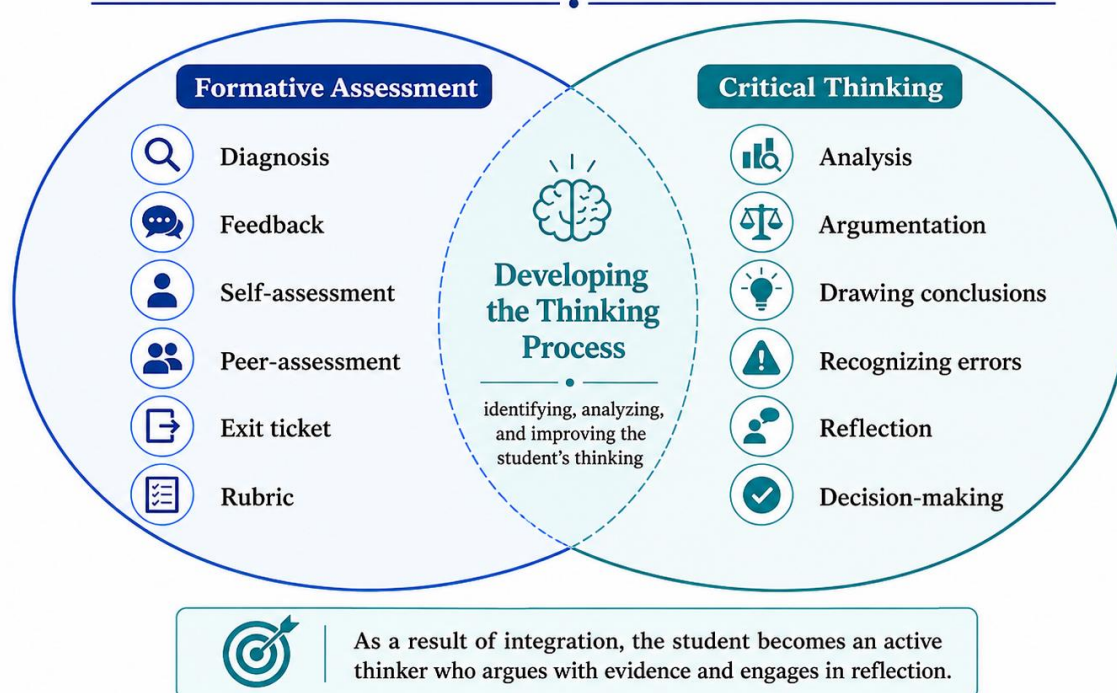
resistance increases in a circuit?" requires the learner to explain a cause-and-effect relationship. Similarly, a question such as "If a light bulb glows dimly, how would you explain the physical reasons for this?" encourages the learner to analyse a problem situation.

Through formative assessment, the teacher observes the following thinking processes of the learner:

- the level of conceptual understanding;
- the ability to apply a physical law;
- skills in working with formulas;
- the level of analysing graphs and experimental results;
- the ability to draw conclusions;
- skills in providing evidence and justification.

Figure 1 illustrates the integration of formative assessment elements and critical thinking components. Formative assessment identifies the learner's thinking process through tools such as diagnosis, feedback, self-assessment, peer-assessment, exit tickets and rubrics. Critical thinking deepens this process through analysis, argumentation, inference, error awareness, reflection and decision-making. Their point of intersection serves the development of the learner's thinking process.

### Integration of Formative Assessment and Critical Thinking Components



**Figure 1.** Integration of formative assessment and critical thinking components

This integration makes it possible to develop critical thinking gradually and systematically.

### 5. Feedback as a Key Tool for Developing Critical Thinking

One of the most important elements of formative assessment is feedback. Feedback is not a simple response such as “correct” or “incorrect.” It is a methodological tool that helps the learner understand an error, analyse it, find the right path, and determine the next step.

For example, if a learner says, “Current is inversely proportional to voltage,” the teacher may immediately mark the answer as incorrect. However, in this case the learner may not understand why the mistake was made. In a formative approach, the teacher gives feedback such as: “You tried to explain the relationship between current and voltage. Now pay attention to Ohm’s law:  $I = U/R$ . Using this formula, try to explain again how current depends on voltage.”

Such feedback does not stop the learner’s thinking process; rather, it redirects it. The learner does not

receive a ready-made answer, but reviews his or her own thinking, recognises the error and independently approaches the correct conclusion.

Effective feedback should meet the following requirements:

- it should be clear and understandable;
- it should be directed at the learner’s work, not at the learner’s personality;
- it should show the error and also indicate a way to correct it;
- it should encourage independent thinking;
- it should indicate the next stage of development.

Thus, feedback develops critical thinking by guiding learners to analyse, justify and improve their own answers.

### 6. Questioning Culture and Critical Thinking

Questioning culture plays an important role in developing critical thinking. Questions asked in physics lessons should not only check knowledge, but also encourage learners to think, analyse phenomena, identify causes and draw conclusions.

| Type of question       | Purpose                           | Influence on critical thinking             |
|------------------------|-----------------------------------|--------------------------------------------|
| Reproductive question  | Recalling knowledge               | Identifies basic concepts                  |
| Explanatory question   | Explaining a phenomenon           | Helps understand cause and effect          |
| Analytical question    | Dividing information into parts   | Teaches comparison of evidence and reasons |
| Problem-based question | Finding a solution to a situation | Develops independent reasoning             |
| Reflective question    | Evaluating one’s own thinking     | Forms self-monitoring                      |

For instance, the question “Why does an object start moving?” requires explanation. The question “How would transport movement change if there were no friction?” encourages learners to make assumptions, analyse a real situation and justify consequences.

In physics lessons, the following questions help activate critical thinking:

- Why?
- What evidence supports your answer?

- How would the result change if the conditions changed?
- What conclusion can be drawn from the graph?
- Did the experimental result correspond to the theoretical law?
- Which physical law supports your idea?

Such questions transform the learner from a passive listener into an active thinking subject.

### 7. Turning the Learner into an Active Participant in the Assessment Process

One important feature of formative assessment is that it actively involves learners in the assessment process. In traditional assessment, learners often participate as objects of assessment: the teacher assesses and the learner receives the grade. In formative assessment,

however, learners monitor, analyse and evaluate their own learning process.

The following methods can be used in this process:

| Formative assessment method | Influence on critical thinking                                 |
|-----------------------------|----------------------------------------------------------------|
| Self-assessment             | The learner analyses his or her own knowledge                  |
| Peer-assessment             | The learner evaluates another learner's reasoning              |
| Exit ticket                 | The learner draws the main conclusion at the end of the lesson |
| "Why?" questions            | The learner learns to explain causes                           |
| Rubric-based assessment     | The learner reasons on the basis of clear criteria             |
| Error-finding tasks         | The learner develops logical analysis                          |

For example, at the end of a lesson, learners may be given the following exit ticket questions:

- What was the most important thing I understood in today's lesson?
- Which question was difficult for me?
- Which physical law can I apply to real life?
- What evidence can I use to justify my answer?
- What should I improve in the next lesson?

These questions help learners evaluate their own thinking, understand their mistakes, and determine their next development pathway.

### 8. Treating Errors as a Source of Development

In traditional assessment, errors are often perceived as negative outcomes. If a learner makes a mistake, the grade decreases and the process ends there. In formative assessment, however, an error is an important source for understanding the learner's thinking process.

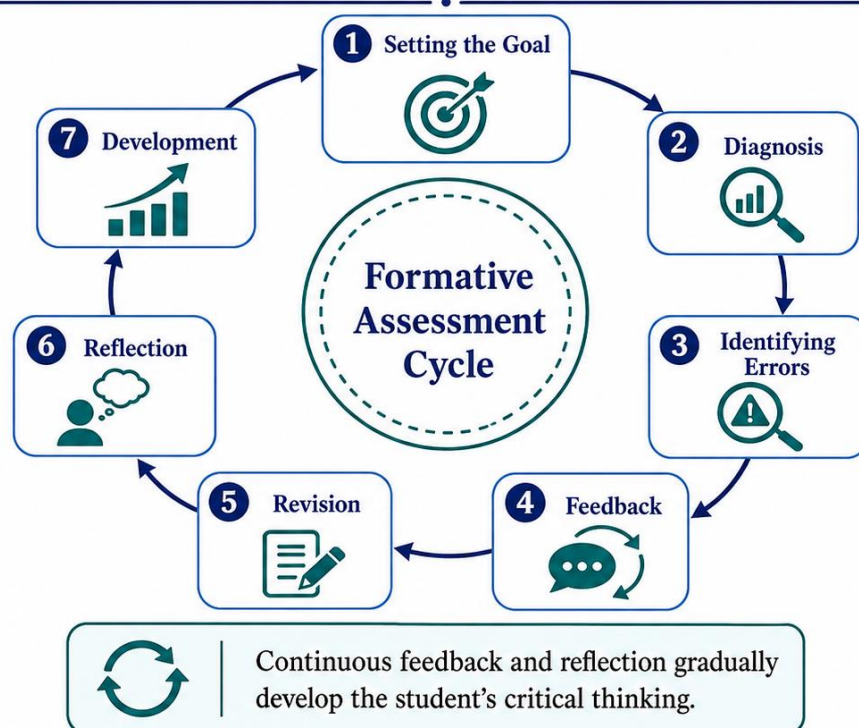
Through errors, the teacher identifies at which stage the learner is experiencing difficulty:

- whether a concept has been misunderstood;
- whether a formula has been applied incorrectly;
- whether there are difficulties with converting units;
- whether a graph has been interpreted incorrectly;
- whether a cause-and-effect relationship has not been understood;
- whether there is a mistake in drawing a conclusion.

For example, if a learner applies the density formula incorrectly, this may not be only a mathematical error. It may indicate that the learner has not deeply understood the physical relationship among mass, volume and density. Therefore, the teacher should not punish the error, but should develop the learner's understanding by analysing it.

In formative assessment, work with errors is organised according to the following cycle: identifying the error → analysing the error → providing feedback → redoing the task → monitoring development.

## The Cyclical Process of Formative Assessment Oriented Toward Developing Critical Thinking



**Figure 2.** The cyclical process of formative assessment oriented toward developing critical thinking

This cycle serves as an effective methodological mechanism for developing the learner's critical thinking.

### 9. Developing Argumentation and Justification Skills in Physics Education

One of the most important indicators of critical thinking in physics is the learner's ability to justify his or her opinion with evidence. In physics lessons, it is important to assess not only the correctness of an answer, but also the reasoning pathway that led to that answer.

Learners may be required to complete tasks such as:

- justify your answer using a formula;
- what conclusion did you draw from the graph?
- did the experimental result correspond to the theoretical law?
- which evidence supports your idea?
- explain the factors that influenced the result;
- explain your conclusion using a real-life example.

Such tasks move the learner beyond mechanical

memorisation and introduce him or her to scientific thinking. Cambridge-style tasks, PISA-type real-life situations, and questions based on graphs and tables require learners to argue, justify and explain.

In a physics lesson, a learner should think in three stages:

- Understanding the phenomenon — what is happening?
- Explaining the cause — why is this happening?
- Justifying with evidence — which law, formula or experiment confirms this?

These stages represent the practical manifestation of critical thinking in physics education.

### 10. Formative Assessment Tasks Based on Physics Topics

To increase the practical value of the article, it is important to connect formative assessment with specific physics topics. The table below presents formative assessment tasks that can be used in physics lessons and the critical thinking skills developed through them.

| Physics topic       | Formative assessment task                                           | Developed critical thinking skill               |
|---------------------|---------------------------------------------------------------------|-------------------------------------------------|
| Ohm's law           | "Why does current decrease when resistance increases?"              | Explaining cause and effect                     |
| Density             | "Why does wood float on water while iron sinks?"                    | Comparison and justification                    |
| Friction force      | "How would transport movement change if there were no friction?"    | Hypothesising and drawing conclusions           |
| Heat transfer       | "Why does a metal spoon heat up faster than a wooden spoon?"        | Evidence-based explanation                      |
| Reflection of light | "How is an image formed in a mirror?"                               | Observation and explanation                     |
| Pressure            | "Why is it easier to walk on snow with skis?"                       | Connecting a real situation with a physical law |
| Mechanical motion   | "How does a motion graph change if the speed of an object changes?" | Drawing conclusions from a graph                |
| Force and motion    | "How does the same force affect objects of different masses?"       | Comparison and identification of regularities   |
| Energy              | "Why does potential energy increase when height increases?"         | Explaining the cause                            |
| Electric circuit    | "If a light bulb glows dimly, what could be the physical reasons?"  | Analysing a problem situation                   |

These tasks direct learners not toward remembering ready-made answers, but toward explaining physical processes, providing evidence and drawing conclusions. As a result, formative assessment appears as a practical tool for developing critical thinking.

### 11. The Author's Methodological Approach

According to the author's approach, formative assessment in physics lessons should perform three main functions in order to develop critical thinking.

First, formative assessment should identify the learner's existing knowledge and conceptual understanding. In this process, introductory questions, mini-tests, conceptual questions and short diagnostic tasks can be used.

Second, formative assessment should activate the learner's thinking process. For this purpose, problem-based questions, experiments, graphs, real-life situations and Cambridge-style tasks serve as effective tools.

Third, through feedback and reflection, formative assessment should guide the learner to reconsider his or her own thinking, understand mistakes and improve answers.

On this basis, formative assessment is regarded not as a control tool, but as a pedagogical mechanism that develops the learner's scientific thinking.

### 12. A Methodological Model for Developing Critical Thinking through Formative Assessment

Within the scope of the study, a methodological model was developed to support the development of students' critical thinking through formative assessment in physics education. This model consists of the stages of diagnosis, activation, argumentation, feedback, reflection and improvement. Each stage is directed toward identifying, supporting and developing the learner's thinking process.

In the methodological model presented in Figure 3, the formative assessment process begins with identifying

the learner's initial knowledge and level of thinking. At the next stage, the learner's thinking is activated through a problem-based question, experiment or real-life situation. In the argumentation stage, the learner defends his or her reasoning on the basis of a formula, graph or experimental results. In the feedback stage, the learner becomes aware of mistakes; in the

reflection stage, the learner evaluates his or her own thinking. In the improvement stage, knowledge and skills are strengthened through redoing tasks and correcting errors.

### Methodological Model for Developing Students' Critical Thinking through Formative Assessment in Physics Education

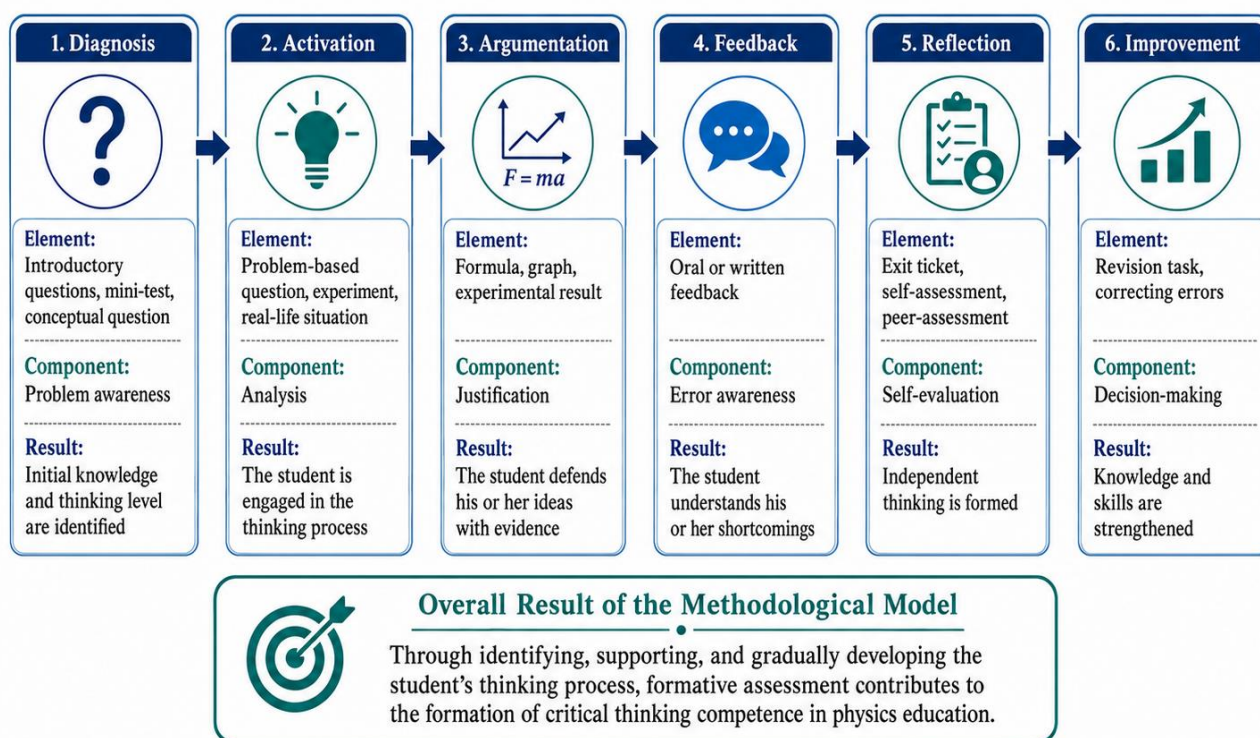


Figure 3. Methodological model for developing students' critical thinking through formative assessment in physics education

The general meaning of the model is that formative assessment forms critical thinking competence in

physics education by identifying, supporting and gradually developing the learner's thinking process.

| Stage         | Formative assessment element                            | Critical thinking component | Expected result                                        |
|---------------|---------------------------------------------------------|-----------------------------|--------------------------------------------------------|
| Diagnosis     | Initial questions, mini-test, conceptual question       | Problem awareness           | Initial knowledge and thinking level are identified    |
| Activation    | Problem-based question, experiment, real-life situation | Analysis                    | The learner is involved in the thinking process        |
| Argumentation | Formula, graph, experimental result                     | Justification               | The learner defends his or her reasoning with evidence |

|             |                                               |                 |                                         |
|-------------|-----------------------------------------------|-----------------|-----------------------------------------|
| Feedback    | Oral or written feedback                      | Error awareness | The learner understands his or her gaps |
| Reflection  | Exit ticket, self-assessment, peer-assessment | Self-evaluation | Independent thinking is formed          |
| Improvement | Redoing the task, correcting mistakes         | Decision-making | Knowledge and skills are consolidated   |

In this model, formative assessment is regarded not as a means of controlling knowledge, but as a means of identifying and developing the learner's thinking process.

### 13. Expected Pedagogical Outcomes

Physics lessons organised on the basis of formative assessment lead to the following pedagogical outcomes:

- students develop the ability to explain physical phenomena through cause-and-effect relationships;
- students learn to use formulas, graphs and experimental results as evidence;
- a culture of recognising and correcting errors is formed;
- students' independent thinking and reflective abilities increase;
- students become accustomed to justifying, defending and reconsidering their answers;
- students develop a more conscious and active attitude toward physics;
- students develop scientific thinking and logical analysis skills.

These outcomes show that formative assessment in physics education performs not only an assessment function, but also a developmental function.

### 14. Discussion

The above analyses indicate that there is a deep methodological connection between formative assessment and critical thinking. Formative assessment monitors the process of learning, while critical thinking improves the quality of this process.

Effective use of formative assessment in physics education directs learners toward the following activities:

- observing a physical phenomenon;

- identifying a problem;
- explaining cause-and-effect relationships;
- applying a formula or law;
- analysing graphs and tables;
- identifying errors;
- drawing evidence-based conclusions;
- reconsidering one's own ideas.

This transforms the learner from a passive recipient of knowledge into an active thinker, researcher and individual capable of managing his or her own learning process.

Formative assessment also improves the teacher's methodological activity. Based on assessment results, the teacher adapts the lesson process, identifies learners' needs and implements an individual approach. This contributes to improving the quality and effectiveness of physics education.

### 15. Practical Recommendations

The following practical recommendations can be proposed for developing students' critical thinking through formative assessment in physics lessons:

- Learning objectives and success criteria should be clearly defined in each lesson.
- Diagnostic questions should be used at the beginning of the lesson to identify learners' prior understanding.
- Students should be asked not only factual recall questions, but also questions such as "Why?", "How can you prove it?", and "What conclusion do you draw?".
- Feedback should be directed at the learner's thinking process and work, not at the learner's personality.
- Errors should be analysed not as negative outcomes, but as sources of development.
- Exit tickets, self-assessment and peer-assessment should be used regularly.

- Tasks based on graphs, formulas, experiments and real-life situations should be used more frequently.
- Students should be trained to justify their answers with evidence.
- At the end of the lesson, learners' self-assessment should be organised through reflective questions.
- The content and tasks of subsequent lessons should be adapted on the basis of formative assessment results.

## **CONCLUSION**

Developing students' critical thinking in physics education is one of the important methodological tasks of contemporary education. Deep mastery of physics requires learners not only to know formulas and laws, but also to analyse them, apply them in real situations, interpret experimental results, draw conclusions from graphs and justify their ideas with evidence.

Formative assessment appears as an effective methodological tool in this process. Its diagnostic, developmental, reflective, feedback-based and evidence-oriented characteristics serve to develop learners' critical thinking step by step.

The methodological model proposed as a result of the study—diagnosis, activation, argumentation, feedback, reflection and improvement—makes it possible to organise formative assessment systematically in physics lessons. Through this model, learners understand their own knowledge, analyse mistakes, reason on the basis of evidence and learn to draw independent conclusions.

Thus, formative assessment can be interpreted as a pedagogical and methodological mechanism for developing critical thinking in physics education. Combining it with Cambridge-style tasks, PISA-type real-life problems, experiments, graphs, formulas and reflective questions contributes to the formation of scientific thinking, logical analysis and evidence-based decision-making skills in students.

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