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**THE FORMATION OF LIFELONG LEARNING COMPETENCES
WITHIN THE PHYSICS LESSON**

532.02 School Didactics (Physics)

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CONCEPTUAL FRAMEWORK OF THE RESEARCH

Relevance and Importance of the Topic

The rapid transformation of knowledge and the expansion of its role in organizing social life require education to develop individuals capable not only of accumulating information, but of understanding, organizing, and using it in variable contexts. This orientation is supported by the educational policy documents of the Republic of Moldova – the Education Code, which aims at the free and creative development of the individual through the development of students' competences, and the Physics Curriculum, centered on the system of competences as an educational outcome. Physics, through its explanatory and relational nature, offers a relevant framework for the development of lifelong learning competences (LLLC), requiring students to correlate concepts, models, and real situations.

Lifelong learning competences take shape as a transversal construct of contemporary education, present in European reference frameworks [64] and in national curricular documents, but the literature review highlights their open character, dependent on the disciplinary and cultural context in which they are formed. The relevance of the topic is also supported by the need to rethink the teaching of physics through constructivist strategies centered on active participation, dialogue, and experimentation, as well as by the requirements of international assessments [54], which emphasize students' ability to transfer concepts to new situations. The research starts from the idea that the formation of LLLC in the physics lesson is determined by the way knowledge is structured and by the didactic mechanisms through which it is put to work.

Description of the Research Situation and Identification of the Problem

The theoretical basis of the research is built from key international contributions dedicated to learning and the formation of competences – lifelong education [30], lifelong learning [28], competences in complex situations [58], and competence as the mobilization of resources [45] – as well as from contributions on the didactic mechanisms of learning: visible learning [41], learning through inquiry [53], big scientific ideas [39], peer instruction and conceptual questions [50], the 5E model [9], problem-based learning [63], scaffolding [74], simulations as cognitive tools [2], and hands-on experiments, alongside the European Framework of Key Competences [64] and the OECD DeSeCo framework [56].

The research also draws on theoretical contributions from the Romanian and domestic academic space regarding the mechanisms of learning and the organization of competences [4, 6, 11, 23, 35-38]. The analysis of related doctoral theses reveals a diversity of competence-based approaches, from curricular design [70] to the use of digital environments [8], [60],

information competence [34], the competence of learning to learn through extramural independent activities, metacognitive competence through didactic communication [32], and creative writing skills and textual competence [31], [51], which reveals the need for an explicit approach to the internal mechanisms through which competences are formed in learning, correlated with the structure of knowledge and the disciplinary specificity.

The Research Problem resides in the fact that, although LLC are assumed as a transversal educational outcome, the concrete didactic mechanisms through which they can be systematically formed within the discipline of physics remain insufficiently clarified: there persists an epistemic discontinuity between the status of knowledge as a coherent conceptual system and the actual organization of learning, in which content, strategies, and assessment function as relatively autonomous planes. From this observation arise the research questions concerning the role of explicit didactic mechanisms, the articulation of the structure of knowledge with didactic strategies, the function of big scientific ideas, the role of conceptual questions and feedback, as well as the conditions under which learning competences become operational at the level of the physics lesson.

The Object of the Research

The object of the research is the didactic process of forming lifelong learning competences within the physics lesson, analyzed through the lens of the triadic structure of knowledge and of integrated didactic strategies oriented toward conceptual understanding and metacognitive reflection.

The Aim of the Research

The aim of the research is to analyze the internal structure and the mechanisms of formation of lifelong learning competences and to operationalize them in the physics lesson, through the use of learning through inquiry and of didactic strategies oriented toward understanding, within an experimentally validated didactic model with an integrative character.

The Objectives of the Research

- Clarifying the conceptual framework of lifelong learning competences and their status as a transversal outcome of education, in relation to the specifics of teaching physics;
- Highlighting the role of big scientific ideas and conceptual questions in structuring learning through understanding and in the formation of lifelong learning competences;
- Explaining the didactic and cognitive mechanisms involved in the formation of lifelong learning competences within the discipline of physics;
- Experimentally investigating the impact of peer instruction on conceptual understanding, metacognition, attitude toward physics, and students' academic success;

- Integrating the student's cognitive progress, the didactic methodology, the development of learning competences, and the disciplinary complexity of the content into a multidimensional structure that describes and supports the formation of lifelong learning competences within the discipline of physics.

The Research Hypothesis

The formation of lifelong learning competences in the physics lesson is determined by the intentional structuring of the didactic process in relation to the components of knowledge and by the coherent integration of teaching, assessment, and feedback strategies. The combined use of learning through inquiry, big scientific ideas, and peer instruction leads to the development of conceptual understanding, metacognition, and attitudes toward learning, generating cognitive progress and the formation of transferable competences. The effectiveness of learning depends on the integrated activation of the cognitive, axiological, and metacognitive dimensions of knowledge, supported by a synergistic didactic approach oriented toward understanding.

Summary of the Research Methodology

The research methodology consists of a set of methods structured on different levels: theoretical methods – scientific documentation, analysis and synthesis, generalization and systematization, conceptual modelling; interpretive methods – correlation of concepts and interpretation of results; praxiological, sociological, and statistical methods – the pedagogical experiment, observation, initial and final testing, surveying, and statistical data analysis. To verify the hypothesis, a formative pedagogical experiment was carried out, based on the differentiated application of didactic strategies, pursuing the integration of conceptual questions, peer instruction, and big scientific ideas in relation to the structure of knowledge and the development of competences. The results were analyzed by comparing students' performance and the evolution of their academic achievement.

The Scientific Novelty and Originality of the Research

- Explaining the formation of lifelong learning competences by relating them to the structure of knowledge, going beyond descriptive approaches and highlighting the cognitive mechanisms that support learning in the teaching of physics.
- Demonstrating the differentiated role of the components of knowledge, in particular the importance of conditional knowledge and the interdependence of the cognitive, axiological, and metacognitive dimensions in students' progress.

- Highlighting the function of big scientific ideas as a core for organizing learning, and the role of conceptual questions and peer instruction in activating, regulating, and consolidating understanding.
- Formulating the concept of didactic synergy, based on the functional integration of teaching, assessment, and feedback strategies and oriented toward cognitive activation and the self-regulation of learning.
- Developing, on the basis of theoretical and empirical results, a pedagogical model structured on four dimensions, each developing in stages, which integrates cognitive progress, didactic methodology, the formation of competences, and the disciplinary specificity of physics.

The Theoretical Significance of the Research results from the deepening and conceptual articulation of the formation of lifelong learning competences in the teaching of physics, by relating them to the structure of knowledge and to the didactic mechanisms that support learning through inquiry. From an integrated perspective, the following key concepts were analyzed:

- *Lifelong learning competences* – the student's ability to learn autonomously, to apply knowledge in new contexts, and to reflect on their own learning process within the physics lesson;
- *The triadic structure of knowledge* – the organization of learning into theoretical, procedural, and conditional knowledge, correlated with axiological and metacognitive dimensions, which support the understanding and application of concepts;
- *Learning through inquiry* – a didactic approach oriented toward investigation, hypothesis formulation, and interpretation of results, through which the student actively constructs an understanding of physical phenomena;
- *Big scientific ideas* – fundamental concepts that structure physics content and organize learning around understanding and transfer;
- *Conceptual questions* – didactic tools used to activate thinking, check understanding, and regulate the learning process;
- *Didactic synergy* – the functional integration of teaching, assessment, and feedback strategies into a coherent approach oriented toward the formation of competences;
- *The 4D pedagogical model* – an integrative didactic framework that articulates cognitive progress, didactic methodology, the development of competences, and the complexity of physics content.

The Practical Value of the Research consists in providing an operational framework for designing and delivering physics lessons oriented toward the formation of lifelong learning competences, through the use of conceptual questions, peer instruction, and the organization of content around big scientific ideas. This framework is supported by the 4D pedagogical model and offers concrete guidelines for integrating learning through inquiry, metacognitive reflection, and formative assessment into didactic activity.

Dissemination of the Research Results was achieved through presentations at national and international scientific conferences, within the sessions of the Republican Methodological Seminar of physics teachers, and through scientific articles published in national and international journals.

Publications on the Topic of the Thesis. The results of the research are reflected in 13 scientific papers, of which: 2 articles in recognized international journals, 3 articles in journals included in the National Register of specialized journals, and 8 articles in the proceedings of international scientific conferences held in the Republic of Moldova.

Structure of the thesis: introduction, three chapters, general conclusions and recommendations, 150 pages of main text, a bibliography of 182 sources, a list of abbreviations, 20 annexes, 28 tables, and 23 figures.

CONTENT OF THE THESIS

The Introduction argues the relevance and importance of the topic, situating the formation of lifelong learning competences within the context of the current requirements of teaching physics. It describes the research situation, the problem, the object, and the aim of the work, along with the objectives, the hypothesis, and the methodology of the investigation, centered on the relationship between the structure of knowledge and the didactic strategies used in the physics lesson. It also presents the scientific novelty, the theoretical significance, the practical value, and the dissemination of the research results.

Chapter 1 “Theoretical-Didactic Aspects Regarding the Need for the Formation of Lifelong Learning Competences” conceptually grounds the notion of competence, through the analysis of the evolution and diversity of definitions found in the specialized literature and in educational documents. It examines key competences in international and national documents, analyzes lifelong learning competences through the lens of their structure and functions, and addresses the relationship between scientific competences and school education. The chapter also outlines the internal structure of lifelong learning competences and their relationship with the didactic strategies used in the physics lesson, concluding with an argument for learning through inquiry, organized around big scientific ideas, as a paradigm for the formation of competences in physics.

Subchapter 1.1 shows that competence-based instruction is a central element of the development of the contemporary school curriculum; the consulted sources show, however, that the term does not originate in the educational sciences, but in the business sphere, from where it was later transferred to management and to education, during the 1970s-1990s [36]. The difficulty of defining competence stems, to a great extent, from its epistemological uncertainty: the concept “is inferred from performance without guaranteeing future success in varied tasks” [43], which explains the multitude of definitions, often contradictory, present in the specialized literature.

Pierre Gillet defines competence as “schemes of action which allow, within a series of situations, the identification and efficient resolution of problems” [33], emphasizing the role of theoretical knowledge as a basis without which the application of skills remains difficult and imprecise. Philippe Perrenoud describes it as a combination of knowledge, skills, and attitudes that allow the effective handling of complex situations, insisting on critical thinking, autonomous learning, and social competences as fundamental dimensions [58]. Marin Manolescu synthesizes these perspectives, showing that a competence presupposes “the integration and adaptation of knowledge, its mobilization and transfer in various situations, the

adjustment of resources and strategies of thought and action, and their refinement as accumulated experiences diversify” [49]. Based on these convergent perspectives, within the thesis, competence is understood as an integrated and dynamic set of knowledge, skills, and attitudes, mobilized contextually to cope with varied situations of life, learning, and social activity.

At the level of policy documents, the European Commission defines key competences as a set of knowledge, skills, and attitudes considered essential for personal development, social inclusion, active citizenship, and employability, updating in 2018 the European Reference Framework with eight key competences, from communication in the mother tongue and multilingual competences to STEM, digital, personal, social and learning-to-learn, civic, entrepreneurial, and cultural awareness competences [64]. In parallel, the OECD proposes, through the DeSeCo project, a three-dimensional classification: the interactive use of tools, interaction in heterogeneous social groups, and autonomous action [56]. At the national level, the concept of key competences has been developed as a transferable and multifunctional set of knowledge, skills, and attitudes necessary for personal development, social inclusion, and professional integration [52], with the Education Code of the Republic of Moldova stipulating that “the main educational objective of the school is the free and harmonious development of the student and the formation of a creative personality, capable of adapting to the changing conditions of life”, a list of key competences which, in the national version, is more extensive than the one recommended by the European Union.

The concept of lifelong learning competences (LLLC) originates in the Faure Report, published by UNESCO under the coordination of Edgar Faure, which established the idea of education as a continuous process, adapted to the rapid changes of society [30]; the principle was taken up again by the European Commission in the document “Key Competences for Lifelong Learning” [64]. The basic functions of LLLC, systematized in the chapter, concern the individual's adaptability to changes in the professional and personal environment, the improvement of employability, holistic personal and professional development, the promotion of autonomous learning, the contribution to the formation of an informed society, and the integration of learning into various life contexts.

Finally, scientific competences are defined convergently by several sources as a foundation of LLLC: the school physics curriculum of the Republic of Moldova structures them on three dimensions, cognitive (fundamental knowledge and concepts), operational (experimentation and investigation skills), and attitudinal (curiosity and responsibility toward the implications of science) [4], while the National Research Council of the USA defines them

as a set of skills necessary to investigate, explain, and interpret natural phenomena [53]. The domestic literature reveals a significant terminological diversity, “scientific competences”, “competences in sciences”, “competences of scientific knowledge” [6], reflecting differences in emphasis between the process of investigation and the practical applicability of knowledge, features that confer upon scientific competences the status of an indispensable foundation for the formation of LLLC.

Subchapter 1.2 shows, describes, and analyzes the way in which lifelong learning competences are internally structured and correlated with the didactic strategies used in the physics lesson. The subchapter starts from the observation that one of the greatest challenges of the educational system is students' low engagement and reduced motivation for learning [42], a weak positive correlation being noted between students' expectations and their evaluation of the educational offer [44]. The memorization paradigm is identified as a factor that perpetuates this discrepancy, while constructivist teaching strategies, through the emphasis placed on the student's cognitive effort, are indicated as a viable solution for developing motivation and interest in learning [1]. Starting from these premises, four research questions are formulated: what is the relationship between LLLC and constructivist didactic strategies; what are the structure and the basic characteristics of LLLC; which LLLC are important for the formation of scientific competence; and which didactic strategies support the formation of LLLC in physics lessons.

To answer the first question, the skills characteristic of each of the eight key competences are identified and correlated with the didactic methods appropriate for their formation in the physics lesson, as well as with the Effect Size (ES) of each strategy on academic performance, according to the theory of Visible Teaching and Learning [41], according to which frontal or conventional teaching, sustained for two years by an experienced teacher, has an $ES = 0.4$; strategies with an ES below this threshold have an effect smaller than the benchmark used in this synthesis, while those with an ES above 0.7 are considered particularly valuable. The correlation is systematized in Table 1, which indicates, for example, for the competence of communication in the mother tongue, strategies such as peer instruction ($ES = 0.74$) or debate and discussions ($ES = 0.82$), for the mathematics, science, and technology competence — reflective learning ($ES = 1.29$), and for the learning-to-learn competence — metacognition and self-assessment ($ES = 0.86$).

Table 1. Alignment between key competences, skills, and didactic methods

Key competences	Skills		Didactic methods	Effect size
1. Communication in the mother tongue	Listening		Active listening, Peer instruction	0.74
	Speaking		Debate and discussions, Cooperative learning	0.82
	Reading		Flipped classroom	0.50
	Writing		Personal journal	0.52
2. Communication in a foreign language	Listening		Online debate and argumentation sessions	0.82
	Speaking			
	Reading		Reading	0.75
	Writing		Summaries of physics texts	0.79
3. Mathematics, science and technology competence	Arithmetic		Mental calculation, estimating results	0.59
	Problem-solving		Problem-based instruction	0.68
	Analysis and critical thinking		Reflective learning	1.29
	Applying knowledge			
4. Digital competence	Accessing	digital information and content	Use of digital and online resources	0.29
	Evaluating		Reflective learning	1.29
	Using		Use of interactive applications	0.47
	Creating		Learning through inquiry	0.40
5. Learning-to-learn competence	Critical thinking		Problem-based learning	0.68
	Research		Reflective learning	1.29
	Self-reflection		Metacognition and self-assessment	0.86
	Adaptability and communication		Cooperative learning	0.55
6. Social and civic competence	Interaction and communication		Cooperative learning	0.55
	Analysis and synthesis		Social engagement projects	0.39
	Cooperation and negotiation		Role-play	0.50
	Mutual respect		Debates and discussions	0.82
7. Entrepreneurial competence	Risk-taking		Active learning	1.28
	Systemic analysis and approach		Problem-based learning	0.68
	Leadership and organization		Mentoring	0.57
	Communication and networking		Interactive playful activities	0.50
8. Cultural sensitivity and awareness	Intercultural respect and dialogue		International collaboration projects	0.82
	Understanding cultural diversity and ways of thinking		Case studies	0.47
			History of science	0.48
	Empathy and understanding		Cooperative learning	0.55

To answer the second question, the structure of LLLC defined by the OECD [56] is analyzed — competences for interacting with the environment, competences for interacting with other people in heterogeneous groups, and the competence to act autonomously — and it is argued that this structure does not directly reflect the fact that LLLC are based on two major clusters: Knowledge (cognitive and physical knowledge and skills) and Communication (emotional and social skills). Correlating these clusters with the four types of intelligence — intellectual, emotional, social, and kinesthetic — the author’s own contribution is formulated: each LLLC rests on four pillars — knowledge, skills, metacognition, and communication — represented graphically in Figure 1.



Fig. 1. The structure of LLLC.

To illustrate how these components are reflected in a concrete teaching situation, the topic “Force – a vector quantity”, taught at the middle-school level, is analyzed, following four stages of didactic design:

First, in accordance with the principle of Big Scientific Ideas [39], lesson planning begins with the formulation of three to four BSIs that the student must master: force is a vector; every vector is characterized by magnitude, direction, and origin; collinear forces are parallel to one another; the action of several forces on a body is described by their resultant.

Second, since BSIs coincide with new vocabulary elements and content units [4], the lesson objectives are formulated, based on the LLLC structure in Figure 1, in terms of what the student must know, be able to do, and understand — summarized in Table 2: under “knows” — the characteristics of a vector and examples of scalar/vector quantities; under “can” — identifying, graphically representing, and adding collinear vectors, measuring force with the dynamometer; under “understands” — the difference between scalar and vector quantities and assessing the correctness of a logical argument. The first three categories form the Knowledge Cluster, while the Communication Cluster consists of enriching active scientific vocabulary (the origin, magnitude, and direction of a vector, collinear forces, resultant force) and developing scientific discourse through practicing logical reasoning.

Table 2. Competence units for the topic “Force – a vector physical quantity”

Competence units	Content units	Learning activities	Didactic strategy
Knowledge. Knows: All the characteristics of a vector // Examples of scalar physical quantities // Examples of vector physical quantities.	• Force as a vector • The characteristics of a vector. • Collinear forces. • The resultant of forces.	Measuring and representing forces on graph paper.	Learning through inquiry
Skills. Can: Identify a vector physical quantity // Graphically represent a vector physical quantity // Add collinear vectors // Associate a vector physical quantity with the measuring instrument.		A problem situation analyzed in a group.	Problem-based learning
Metacognitive skills. Understands: The difference between scalar and vector physical quantities // The correctness of a statement.		Assessment and self-assessment activity. Debates between groups.	Reflective learning
Communication skills. Can formulate and present: Own conclusions and reasoning using the new scientific vocabulary elements assimilated during the lesson.			

Third, the didactic strategies with the highest Effect Size are chosen for these competence units: reflective learning (ES = 1.29), metacognition (ES = 0.86), debates and discussions (ES = 0.82), cooperative learning (ES = 0.82), their simultaneous application generating a cumulative effect, called the synergy of didactic strategies.

Finally, these strategies are concretely operationalized: the students study in groups the action of several forces on a body, graphically represent the forces, communicate the group's results and conclusions, and each student records their own conclusions in the Personal Journal.

Subchapter 1.2 concludes with the observation that strategies characterized by an Effect Size above the reference threshold of 0.4 significantly favor the formation of lifelong learning competences, the Effect Size being treated not as a prescriptive criterion, but as an epistemic benchmark for selecting and combining didactic strategies, adaptable to the disciplinary specifics and to the educational context.

Subchapter 1.3 shows that the strategies for forming LLLC belong to constructivist pedagogies (inquiry-based, reflective, problem-based, cooperative learning), whose effectiveness increases with the amount of feedback given to the student, according to the theory of Visible Teaching and Learning [41]. Inquiry-Based Science Education (IBSE) [12] is

introduced as an approach organized around the phases of the 5E model and big scientific ideas (BSIs), fundamental concepts that anchor learning [39].

It is argued that BSIs can be interpreted both as cognitive objectives of the lesson and as competence units [18], forming a conceptual chain in which the absence of a link affects the student's progress in the short term and, in the long term, distorts their image of the world, BSIs thus functioning as a “vehicle” for the transfer of knowledge [73]. On this basis, two categories of skills for interacting with knowledge are distinguished [74]: basic skills (observation, measurement, classification, prediction) and integrated skills (logical thinking, planning, hypothesis formulation, data interpretation). The shift from mechanical memorization to learning through understanding is made possible precisely by practicing these skills, the subchapter finally emphasizing that understanding the physical meaning of concepts underlies a positive attitude toward learning, with an effect on performance that, according to some authors, is stronger than that of the student's IQ [62].

The theoretical results of Chapter I are described in the author's paper [19] “*Constructivist strategies for the formation of lifelong learning competences*”.

Chapter 2 “Methodological Foundations for the Formation of Lifelong Learning Competences within the Middle-School Physics Lesson” is devoted to the methodological grounding of the process of forming LLLC in middle-school physics lessons. It analyzes the development of epistemological, praxiological, axiological, and metacognitive knowledge, highlighting the complementary role of these dimensions in building deep and durable scientific learning. It is demonstrated that didactic projects based on science learning through the inquiry method provide an appropriate pedagogical framework for the formation of LLLC, through the integration of investigation, data collection and analysis, and presentation and debate of results, and the application of the concept of big scientific ideas in the development of these projects highlights the teacher's role as a facilitator of the investigative process.

Subchapter 2.1 starts from the observation that the accelerated expansion of the information universe and the digital transformation of the labor market require a shift from the paradigm of knowledge accumulation to that of competence development, given that accurately anticipating the knowledge and skills needed in the long term is becoming increasingly difficult. Two objectives that remain constant in the teaching of physics are retained: the development of a scientific understanding of the world and the formation of lifelong learning competences, the latter being the core of the chapter, exemplified through the chapter “Field Interactions” from the 9th grade. It is recalled that, at the European level, the concept of key competences was officially introduced in 2007 and updated in 2018 through a new reference framework [64], its

evolution in the European context and its implementation in the domestic curriculum being analyzed in detail in the specialized literature [35].

For the operationalization of key competences in the physics lesson, knowledge is structured into three components: epistemological (theoretical knowledge or the understanding of concepts and phenomena), praxiological (practical application skills for problem-solving), and axiological (appropriate attitudes, values, and motivations) [64]. The OECD definition of competence is adopted as “the mobilization of knowledge, skills, attitudes and values, along with a reflective approach to learning processes, to engage with and act in the world” [54], physics being presented as a discipline that, by its nature, ensures the integration of the three components of knowledge. Three principles for physics teaching oriented toward LLLC follow from this definition: applying knowledge in real contexts, developing analytical and experimental skills through discovery, and cultivating a reflective attitude that enables students to assess their own progress. The correlation is illustrated between the physics-specific competences from the national curricular documents, such as analyzing and interpreting data related to physical phenomena while displaying critical thinking [4], and the key competences defined by the OECD, which shows that the triadic structure of knowledge is not a theoretical abstraction but a tool directly applicable to didactic design in physics.

The correlation between LLLC and physics competences is also analyzed starting from the results of the PISA assessments, which reveal significant difficulties among students from the Republic of Moldova: approximately one in three 15-year-old students cannot identify the main idea of a text or extract specific information; one in two fails to solve simple applied mathematics problems (currency conversions, length comparisons, interpreting a table or graph); and 58% of students cannot use everyday knowledge to interpret the data of a simple experiment carried out in class, encountering difficulties in formulating scientific questions and in drawing conclusions based on accumulated knowledge. These data are interpreted as an indication that current didactic methods fail to facilitate the development of the necessary competences, especially in the absence of active learning based on inquiry and experimentation, the teaching-learning process remaining, for many students, opaque due to the lack of constant feedback and a competence-centered approach. On this basis, it is emphasized that students are not sufficiently supported in integrating theoretical knowledge into practical contexts or in developing problem-solving skills [37], reaffirming the need to reform the didactic process toward transferable competences [38], [67].

Subchapter 2.2 starts from the idea that school must equip students with LLLC for continuous learning, which requires the explicit integration of this objective into the school

curriculum. It is illustrated how physics textbooks from Romania and the Republic of Moldova already contain active sequences of the type *Observe, Experiment, Memorize, Apply* in the Romanian textbook, and respectively *Solve the situation, Check your knowledge, Analyze the situation* in the Moldovan one [5], but a discrepancy is also observed between the competence objectives of the curriculum and the actual content of the traditional textbooks, which is insufficiently contextualized in practice.

Subchapter 2.2 introduces the concept of Didactic Synergy, defined as the functional integration, within a unified approach, of several strategies, such as: pre-learning activities (Flipped Classroom), interactions among peers (Peer Instruction), and learning through inquiry, which generate improvements in scientific language, problem-solving capacity, and the engagement of students with different performance levels. For synergy to be effective, three principles are formulated: at least one method must activate cognitive effort, one must stimulate metacognitive reflection, and one must ensure visible and immediate feedback, correlations summarized in Table 3 (for example, peer instruction — 0.75; cognitive task analysis — 1.29; the Jigsaw method — 1.20), according to Hattie's synthesis of research-based strategies (Hattie, 2009).

Table 3. Effect size for different didactic methods

Type of method	Learning method and effect		Teaching method and effect	
Cognitive activation	Peer instruction	0.75	Cognitive task analysis	1.29
	Repetition and memorization	0.74	The "Jigsaw" method	1.20
	Motivation and deep approach	0.69	Strategies for integration with prior knowledge	0.93
	Cognitive independence	0.68	Educational support	0.82
Metacognitive	Self-assessment of grades	1.44	Summarizing	0.79
	Piagetian programs	1.28	Planning and prediction	0.76
	Seeking help	0.72	Assessment and reflection	0.75
	Self-verbalization and self-questioning	0.55	Elaboration and organization	0.75
Feedback-based	Teacher estimates of student performance			1.29
	Response to intervention			1.29
	Transfer strategies			0.86
	Guided discussions			0.82
Traditional teaching method				0.40

The concept is applied to the model of a lesson that integrates four methods: Flipped Classroom [3], Peer Instruction with conceptual questions [24], the 5E Model [10], and the early physics approach — compared in Table 4, with effect sizes (Cohen's d) ranging from 0.50 (Flipped Classroom) to over 1.4 for the 5E Model [59].

Table 4. The component strategies of the *Didactic Synergy* concept and their observed effects.

Didactic strategy	Role of the strategy	Effects of the strategy	Effect size (Cohen's d)
Flipped Classroom	Activates prior knowledge and optimizes class time for interactive activities	Increased motivation and engagement; active participation in class	0.50
Peer instruction with conceptual questions	Facilitates the confrontation of ideas and the correction of misconceptions through collaboration	Improved conceptual understanding and scientific language	0.74
The 5E Model	Provides a sequential learning structure (Engage, Explore, Explain, Elaborate, Evaluate)	Stimulates problem-solving and continuous feedback	0.8 – 1.13
Early physics approach	Ensures the transition from mathematical representations to physical concepts and scientific expression	Consolidating the use of formulas and developing scientific reasoning	0.3

The integrated structure of the lesson, with the Engage–Explore–Explain–Elaborate–Evaluate phases and the methods corresponding to each phase, is systematized in Table 5.

Table 5. Structure of the lesson organized according to the concept of didactic synergy.

Lesson phase	Method	Core activity
Phase 0	Flipped Classroom	Prior review of content at home (10–18 minute educational video)
Engage, 7 min	Peer Instruction	Introductory frontal demonstration and the first conceptual question
Explore, 8 min	Learning through inquiry	Practical investigation, group discussion, hypothesis formulation
Explain, 15 min	Peer Instruction	Teacher-guided virtual experiment and the second conceptual question
Elaborate, 10 min	Early physics approach	Interpreting formulas, graphs, and tables, connecting to prior concepts
Evaluate, 5 min	Learning through inquiry	Metacognitive questions and an individual reflection task.

The role of student autonomy is emphasized, supported by the Flipped Classroom and by the continuous feedback obtained through digital response systems (clickers) and through metacognitive questions [47], as well as the strong correlation between laboratory activity grades and final assessment grades. The limitations of the approach are also acknowledged: the transfer of mathematical competences into physics remains a vulnerable area, especially in middle school [71], and the simultaneous integration of the four methods involves considerable planning effort, requiring continuous adaptation to the real dynamics of the class [66]. The subchapter concludes by situating Didactic Synergy in relation to the transversal competences of the 21st century (learning autonomy, scientific reasoning, coherent scientific language) recognized as such in European educational policy documents [64].

Subchapter 2.3 places at the center of the analysis the pedagogical concept of Big Scientific Ideas (BSI), a central element of Inquiry Based Science Education (IBSE) [12], [23], [39]. BSIs are defined as the essential notions that the teacher selects for each physics lesson — usually three to four per lesson — to guide the process of conceptual understanding, and can be equated with the cognitive objectives of the lesson or with competence units [18]. The set of BSIs for a chapter or course is treated as a conceptual chain, in which the absence of a link weakens the whole and compromises both the immediate acquisition of knowledge and the formation of a coherent picture of the natural world; BSIs thus function as "vehicles" for the transfer of knowledge [73] and as a starting point for two categories of skills for interacting with knowledge — basic (observation, classification, measurement, prediction) and integrated (logical thinking, planning investigations, hypothesis formulation, data interpretation) [74]. Within a transdisciplinary framework, BSIs from related disciplines interact with and influence one another, contributing to the formation of systemic thinking, and shifting the center of gravity of learning away from mechanical memorization toward the active construction of knowledge is considered the main way in which BSIs contribute to the formation of LLLC [61].

An empirical result of the author's own [15] is also presented, structured around two research questions: how can BSIs be used so that students develop a deep and coherent understanding of new concepts (the BSI–learning through understanding relationship), and to what extent does the level of conceptual understanding contribute to the formation of LLLC (the learning through understanding–LLLC relationship).

The methodological approach included six formative assessments and one summative assessment, digitized through the Turning Point platform (true/false, multiple-choice, and matching items, with four answer options, one of which was correct, the probability of answering three consecutive items correctly by chance alone being 1.56%), applied to a sample of 12 ninth-grade students from the “Vasile Badiu” middle school in Măgurele, during the study of the chapter “Field Interactions” [4]. The content of the chapter was organized into four IBSE projects, on the topic “Field Interactions”: the Gravitational Field, the Electrostatic Field, the Magnetic Field, and the Solar System, each centered on 2-3 BSIs and structured in five phases: question, hypothesis, experiment, model, application. Conceptual understanding was also tested through graphically illustrated conceptual questions, for example, the mutual orientation of two conductors carrying opposite currents (Fig. 2–3, the Ampère force) or the deflection of a negatively charged particle entering a magnetic field (Fig. 4–5, the Lorentz force).

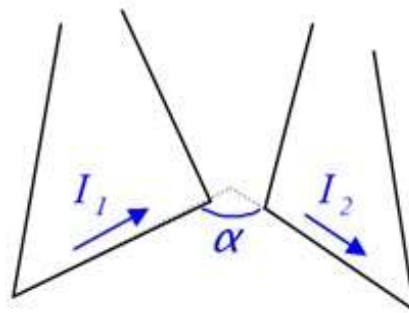


Fig. 2. Conceptual question on the Ampère force.

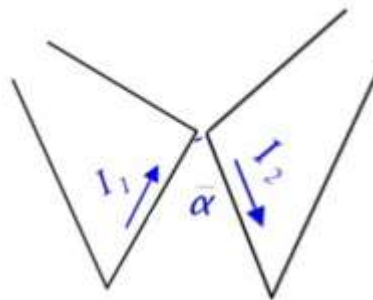


Fig. 3. The answer to the conceptual question on the Ampère force.

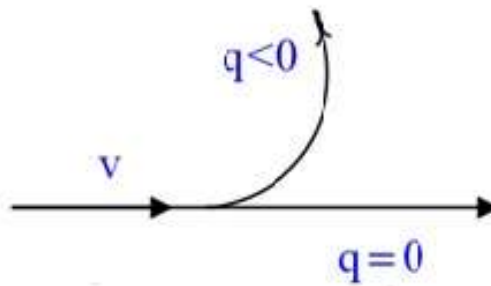


Fig. 4. Conceptual question on the Lorentz force.

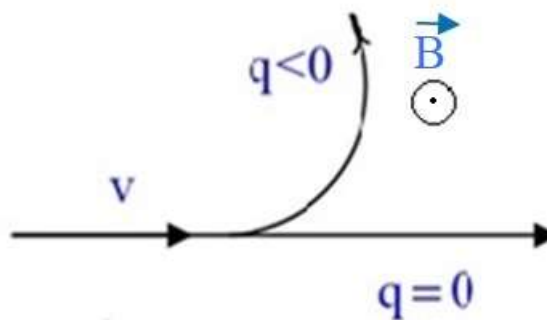


Fig. 5. The answer to the conceptual question on the Lorentz force.

The results of the formative assessments, summarized in Table 6, show marked heterogeneity in understanding of the topic: for “The Law of Universal Attraction”, 80% of students answered the first item correctly and 60% the second, but only 10% understood the inverse relationship between force and the square of the distance (58% consistent understanding of the topic); for “Coulomb’s Law”, 83% correctly identified the dielectric permittivity, but only 8% the dependence of force on distance, 42% wrongly attributing a universal character to electrostatic forces (33% consistent understanding); for “The Electrostatic Field”, no student answered the first item correctly, but 75% and 100% answered the next two correctly (75% consistency); while for “The Action of the Magnetic Field on Charges and Currents” the highest level was recorded — 92% consistent understanding, although a third of the students got the direction of the magnetic induction vector wrong.

Table 6. Results of the formative assessments for the Field Interactions chapter

Topic	I ₁	I ₂	I ₃	P _e
The Law of Universal Attraction	80%	60%	10%	58%
Coulomb's Law	42%	83%	8%	33%
The Electrostatic Field	0%	75%	100%	75%
The Action of the Magnetic Field on Charges and Currents	58%	67%	92%	92%

The summative assessment (Table 7, Figure 6) confirmed the consolidation of declarative knowledge — over 90% of students correctly identified the units of measurement — but revealed persistent difficulties in application: only 33.3% correctly solved the problem on Coulomb's law, 41.6% the one on the magnetic field, and only 33.3% correctly determined the direction of the Lorentz force.

Table 7. Classification of items by type of knowledge and results of the summative assessment

No.	Item type	Content	Type of knowledge	Assessment results
1	Multiple choice	The Law of Universal Attraction	Conditional (involves proportionality relationships, contextual application)	75%
2	Multiple choice	Coulomb's Law	Declarative (scientific fact)	100%
3	Multiple choice	Direction of the force in an electrostatic field	Conditional (applying the rule to a negative charge)	66.6%
4	Matching	Physical quantities and units of measurement	Declarative (definitions and factual association)	91.6%
5	Problem	Electrostatic force	Procedural (formula application)	33.3%
6	Problem	Magnetic field	Procedural	41.16%
7	Problem	Lorentz force (left-hand rule)	Conditional (determining the direction of the Lorentz force depending on context)	33.3%

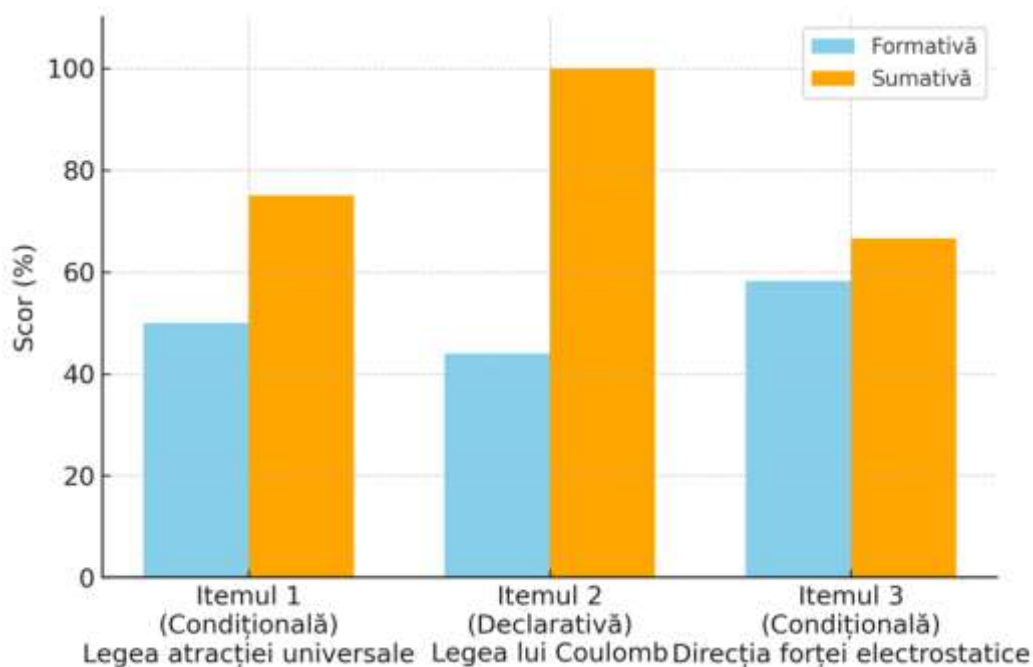


Fig. 6. Comparison of the formative and summative assessment results

The formative–summative comparison nevertheless shows notable progress where immediate feedback explicitly targeted a BSI — from 50% to 75% for the force–distance relationship, and from 44% to 100% for clarifying the nature of the Coulomb force.

The conclusion of the subchapter is that a clear and visible definition of BSIs, supported by permanent formative assessment and immediate feedback, constitutes the basic condition for authentic cognitive progress, empirically confirming (even on a limited sample) the link between organizing content around BSIs, understanding through comprehension, and the formation of lifelong learning competences.

Subchapter 2.4 argues that the process of learning physics is not reduced to the accumulation of facts and formulas, but requires the formation of a coherent set of cognitive and attitudinal structures, theoretical, axiological, and metacognitive knowledge being treated as complementary dimensions of a unified educational process [48]. In the context of competence-centered education, the emphasis shifts from *what* the student learns to *how* and *why* they learn [64], physics (a discipline with a high degree of abstraction and theoretical interdependence) simultaneously requiring deep understanding, internal motivation, and effective learning strategies [68].

Regarding theoretical knowledge, following Lebedev’s model [46], scientific knowledge is structured into four interdependent levels — perceptual, empirical, theoretical, and meta-theoretical — exemplified for physics (free fall observed directly at the perceptual level; determining mass by weighing at the empirical level; formulating the equations of uniformly accelerated motion at the theoretical level; discussions on the limits of classical mechanics relative to relativity at the meta-theoretical level), summarized in Table 8, “Levels of scientific knowledge in physics” and organized graphically in Fig. 7.

Table 8. Levels of scientific knowledge in physics

Level of knowledge	Description	Examples from physics
Perceptual	Direct observation of phenomena (e.g., free fall, the propagation of sound).	The gravitational pendulum experiment in class.
Empirical	Collecting data and establishing relationships (e.g., the dependence of t on h and g).	Determining the mass of a body by weighing and/or applying the formula $F = m \cdot a$.
Theoretical	Formulating laws and models (e.g., Newton's law, the atomic model).	Formulating the equations of uniformly accelerated motion.
Meta-theoretical	Analyzing paradigms, reflecting on the limits of theories (e.g., relativity vs. classical mechanics).	Discussions on the validity of classical models in a quantum context.

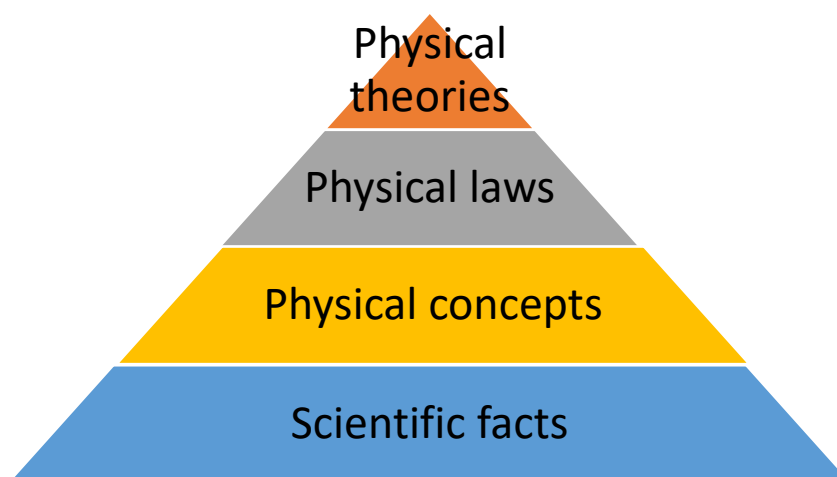


Fig. 7. Organization of the levels of knowledge in physics

The structure is correlated with the grouping of content in the national curriculum into facts, concepts, laws, and theories. The teacher's role for each component of theoretical knowledge is detailed in Table 9, from presenting explanatory models and connecting theory to experimental observations, to clarifying concepts through analogies and checking understanding through application activities.

Table 9. The teacher's role in forming the components of theoretical knowledge

Component of theoretical knowledge	The teacher's role
Physical theories	To present coherent explanatory models and the history of their development; to connect theory to experimental observations.
Physical laws	To formulate laws clearly and exemplify their application in various contexts; to encourage their use in reasoning and problems.
Physical concepts	To clarify the meaning of concepts through analogies, examples, and multiple representations; to check understanding through application activities.
Scientific facts	To present relevant experimental data and show how it supports theories; to encourage curiosity about objective reality.

Axiological knowledge is defined as the value dimension of learning — the student's beliefs, attitudes, interests, and motivations toward science — with a direct impact on engagement and the capacity to transfer knowledge, the central objective being the formation of a positive attitude toward science and the internalization of research values: curiosity, rigor, intellectual honesty, openness to evidence. The correlation between the components of axiological knowledge is illustrated in Figure 8, and the teacher's role — creating attractive contexts, valuing effort, highlighting the social relevance of physics, sustaining a positive atmosphere — is summarized in Table 10.

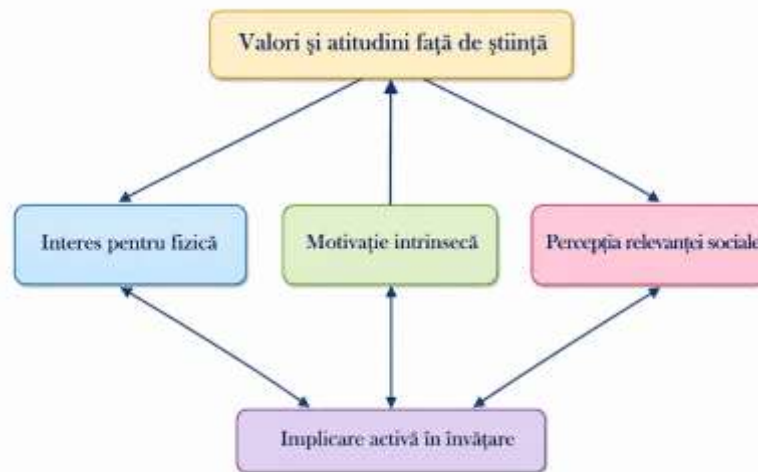


Fig. 8. Correlation between the components of axiological knowledge.

Table 10. The teacher's role in forming the components of axiological knowledge.

Component of axiological knowledge	The teacher's role
Interest in physics	To create attractive and engaging contexts for teaching; to connect content to students' reality.
Intrinsic motivation	To value effort and personal progress; to offer autonomy and choices in learning activities.
The social relevance of physics	To highlight the applicability of physics in everyday life and in society; to use current examples.
Attitude toward physics	To sustain a positive and encouraging atmosphere; to reduce anxiety about the subject through support and constructive feedback.
Active engagement in learning	To organize interactive activities, experiments, and collaborative projects; to encourage participation and initiative.
Beliefs and values	To promote critical thinking and scientific ethics; to discuss the social responsibility of scientific knowledge.

Metacognitive knowledge is treated as the foundation of self-regulation, reflection, and the transfer of knowledge to new situations [69], [72], its structure and interactions being illustrated in Figure 9 and detailed in Table 11, with the corresponding role of the teacher summarized in Table 12.

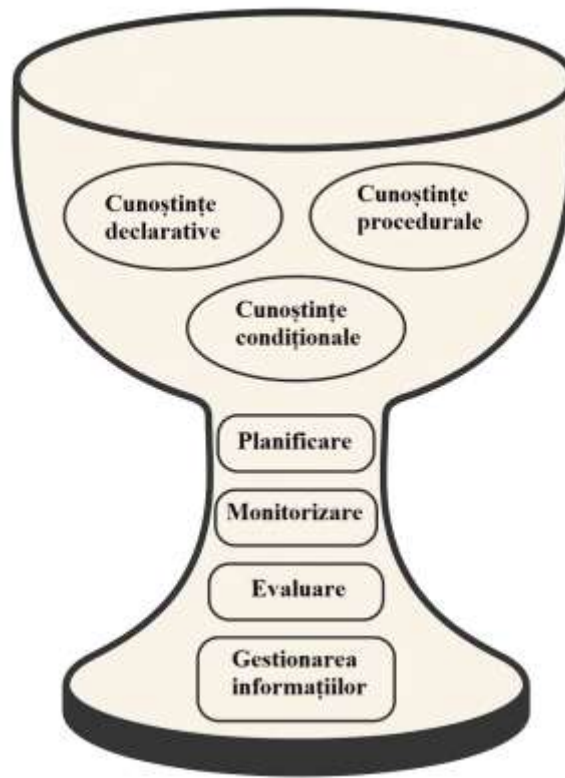


Fig. 9. The basic components of knowledge

Table 11. Instruments for assessing students' level of metacognition in physics

Assessment instrument	Dimensions assessed	Types of items
The Metacognitive Inventory in Physics [69]	1. Knowledge of one's own cognition 2. Planning one's own learning 3. Monitoring one's own learning 4. Evaluating one's own success 5. Adjusting one's own learning strategies 6. Managing information.	Statements on a Likert scale (1–5), applied after problem-solving
The Extended Metacognitive Questionnaire [72]	1. Declarative knowledge 2. Procedural knowledge 3. Conditional knowledge 4. Planning 5. Monitoring 6. Evaluation 7. Debugging 8. Managing information.	50 items grouped into categories, applicable pre/post task-solving

Table 12. The teacher's role in cultivating metacognition.

Metacognitive dimension	The teacher's role
Declarative knowledge	To explicitly present concepts and terminology; to encourage questions and concept maps.
Procedural knowledge	To model the steps of solving, to encourage cognitive routines and analogies.
Conditional knowledge	To explain when and why certain laws or alternative methods apply.
Planning	To encourage goal-setting and the formulation of plans for solving problems.
Monitoring	To check progress and use questions such as "What have you understood so far?"
Evaluation	To use rubrics, self-assessments, and reflections on the process, not only on the outcome.
Debugging	To turn mistakes into learning opportunities and support error analysis.
Managing information	To train students in selecting, organizing, and integrating information from varied sources.

The empirical result shows that, for a sample of 110 seventh-grade students, equally distributed by gender (55 girls, 55 boys), data were collected through questionnaires on metacognition, attitude, and academic success, whose descriptive statistics (Table 13) and graphical distributions (Fig. 10–12) confirm solid statistical support for the relational analysis. Regression analysis shows that metacognition explains about 25% of the variation in academic results ($R(H1) = 0.256$), and attitude about 23% ($R(H1) = 0.234$) — in other words, higher metacognition scores are associated with higher academic achievement.

Table 13. Descriptive statistics for metacognition, attitude, and academic success

	Metacognition		Attitude		Assessment	
	B	G	B	G	B	G
No. of students	55	55	55	55	55	55
Mode	2.967	3.012	3.082	3.728	5.502	6.407
Median	3.100	3.100	3.300	3.600	6.000	6.500
Mean	3.182	3.262	3.395	3.558	6.118	6.409
Std. Deviation	0.474	0.611	0.558	0.551	1.475	1.316
Shapiro-Wilk test	0.974	0.958	0.973	0.948	0.939	0.982
P-value of Shapiro-Wilk	0.281	0.050	0.249	0.019	0.008	0.589
Minimum	2.300	2.000	2.300	2.700	4.000	3.500
Maximum	4.300	4.900	4.700	4.700	10.000	10.000

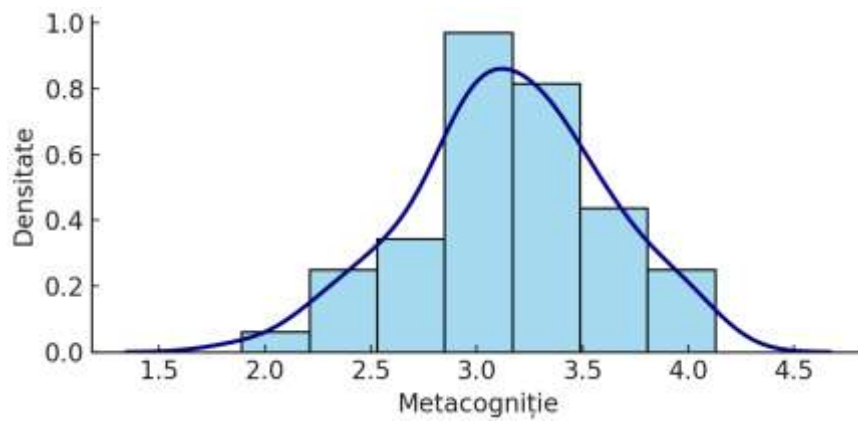


Fig. 10. Distribution of students by level of metacognition.

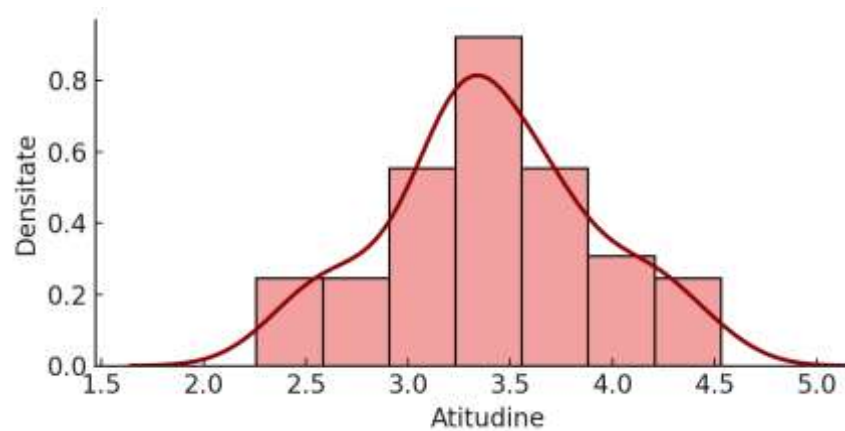


Fig. 11. Distribution of students by level of attitude.

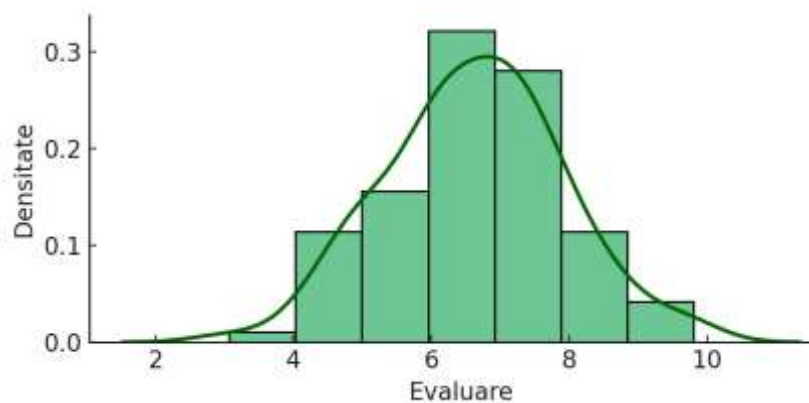


Fig. 12. Distribution of students by assessment results.

Metacognition and attitude are strongly associated ($R(H1) = 0.534$ — over 50% of the variation in one is explained by the other). However, the graphs in Fig. 13–14 also reveal cases of students with high metacognition and attitude but low grades, attributable to factors such as assessment stress, ineffective didactic methods, or extracurricular social conditioning.

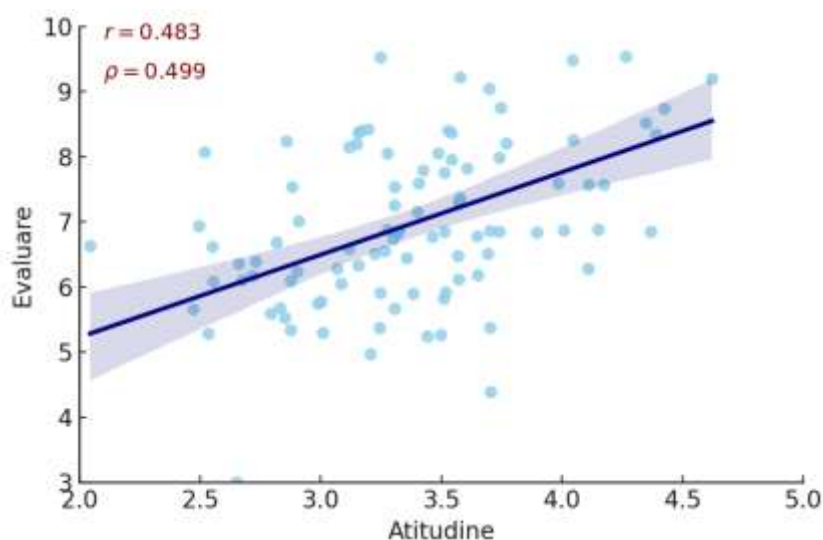


Fig. 13. Correlation between attitude and assessment results.

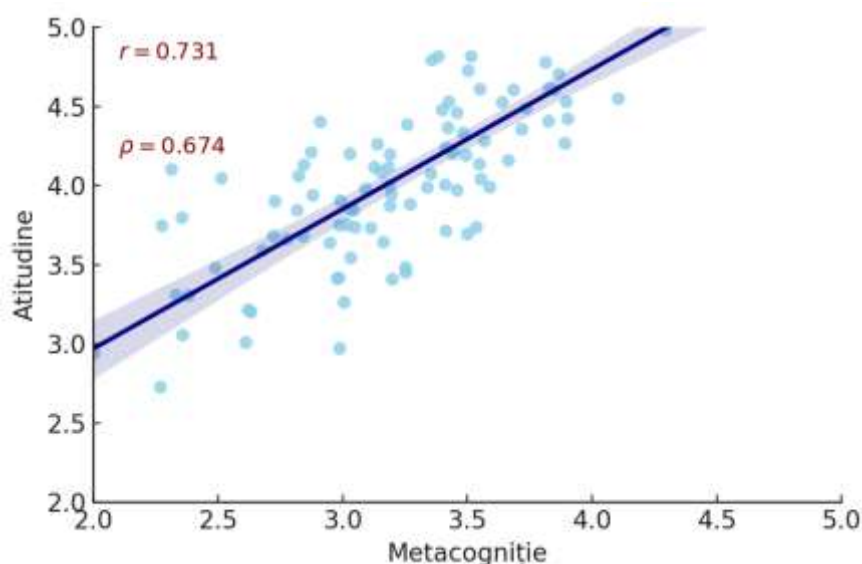


Fig. 14. Correlation between attitude and metacognition.

Thus, students' progress in physics is explained by the systemic interaction of the three dimensions of knowledge and by the way the teacher makes didactic use of them, the transition from factual knowledge to metacognitive reflection not being a linear process, but dependent on the successive activation of higher levels of understanding, the empirical results confirming a stable positive relationship between metacognition, attitude, and academic success, the strongest being that between metacognition and attitude.

The main results of Chapter II are presented in the following papers by the author [18] *"The formation of key competences in the teaching of the field interactions chapter"*, [15] *"The concept of big scientific ideas and its application to the formation of lifelong learning competences"*, [13] *"Comparative analysis of the curriculum and physics textbooks for the 7th grade from Romania, Russia, and the Republic of Moldova from the point of view of supporting*

the concept of lifelong learning competences”, [17] *“Enhancing Science Competence: Evaluating the Effects of Peer Instruction and Conceptual Questions on Theoretical, Axiological, and Applied Knowledge in Physics Education*”, [27] *“The impact of applying the concepts of big scientific ideas and conceptual questions in teaching Electrokinetics in lower secondary education*”, [22] *„Integrating Black Holes and Gravitational Waves into School Physics”*.

Chapter 3 “The Pedagogical Model for Forming Lifelong Learning Competences in the Physics Lesson” constitutes the empirical core of the thesis, synthesizing the research results by investigating the relationship between lifelong learning competences and the structure of scientific knowledge. The triadic structure of knowledge — theoretical, applicative, and axiological — is identified and operationalized, used both as a conceptual foundation and as an evaluation scheme for the impact of the didactic intervention based on Peer Instruction (PI) and Conceptual Questions (CQ). The effects of this intervention are analyzed through a pre-test/post-test design carried out over the course of a school year, in the physics discipline, in 7th grade classes, the chapter culminating in the development of the 4D Pedagogical Model, the integrative synthesis of the entire research, whose applicability is demonstrated in the design of physics lessons.

Subchapter 3.1 argues that the formation of LLLC in the physics lesson cannot be dissociated from the balanced development of three types of knowledge: theoretical (understanding fundamental concepts and principles, as a benchmark for explaining phenomena and the logical structuring of ideas), applicative (transferring principles into problem-solving and experimental activities, supported by the use of information technologies), and axiological (intellectual ethics, responsibility, perseverance, collaboration). It is emphasized that ignoring one of these dimensions produces an incomplete formation: a lesson focused exclusively on repeating concepts or on algorithms does not form durable learning competences.

As a didactic mechanism for operationalizing this triad, the Peer Instruction method is analyzed [24], applied through sequences structured around Conceptual Questions: individual reflection, first vote, discussion in pairs, second vote, collective clarification, a structure summarized in Table 14.

Table 14. Structure of a lesson sequence within the Peer Instruction method

Phase	Duration	Actions
Introduction	5 min	The teacher introduces one of the main concepts of the lesson.

Conceptual Question	$\frac{1}{2} - 1$ min	A thought-provoking question, related to the topic, is posed to the students. The questions are qualitative in nature, with four or five answer options, and do not require mathematical calculation.
Individual reflection	1 min	Students think individually about the question and vote.
First vote	–	Students vote. The teacher does not give the correct answer after the results are displayed.
Discussion in pairs	2 min	Students discuss their answers in pairs, explaining their reasoning and comparing their understanding.
Second vote	–	Students vote again. The teacher displays the correct answer after the vote.
Clarification	2 min	The teacher moderates a whole-class discussion. Students share their conclusions, and the teacher clarifies any misunderstandings.
Reassessment	4 min	A control question or problem is posed to assess understanding after discussion and clarification.

A concrete example of a CQ is illustrated for the chapter “Rotational Equilibrium. Simple Mechanisms” (the lever problem with arms of 2 m and 1 m), the logical chain Cognitive Objectives – BSI – CQ [39] being emphasized. The efficiency and accessibility of the method for teachers are discussed, the role of paired discussion in the formation of metacognition [57], as well as the gap documented in the literature between scientifically argued teaching and actual classroom practice [54], a gap that traditional assessments, centered on factual performance, fail to capture.

The experiment itself was carried out during the 2023-2024 school year at the “Mihai Eminescu” Theoretical Lyceum in Ungheni, across four 7th-grade classes (110 students, 55 boys and 55 girls). PI was applied in all physics lessons, with 2-3 CQs per lesson; theoretical knowledge was assessed by comparing the summative results from the first chapter (“Motion and Rest”) and the last (“Rotational Equilibrium”), according to the assessment framework approved by the ministry [7]; conditional knowledge (metacognition and attitude) was assessed pre/post through the questionnaire from the authors' previous research [16], structured on three components of metacognition (cognitive knowledge, self-regulation, strategy application) and three of attitude (attitude proper, values, ethics); applied knowledge was assessed on the practical items of the summative tests [29]. The descriptive statistics are summarized in Table 15.

Table 15. Descriptive statistics for metacognition, attitude, and academic success

	Metacognition				Attitude				Academic success			
	Pre-test		Post-test		Pre-test		Post-test		Pre-test		Post-test	
	B	G	B	G	B	G	B	G	B	G	B	G
Valid	55	55	55	55	55	55	55	55	55	55	55	55
Median	3.100	3.100	3.300	3.700	3.300	3.600	3.600	3.900	5.000	6.000	7.000	7.000

Mean	3.182	3.262	3.278	3.615	3.395	3.558	3.515	3.698	5.291	5.618	7.436	7.455
Std. Dev.	0.474	0.611	0.671	0.681	0.558	0.551	0.615	0.498	1.843	1.533	1.014	0.978
Shapiro-Wilk	0.970		0.963		0.965		0.961		0.961		0.901	
P-value	0.014		0.004		0.005		0.003		0.003		<0.001	
Minimum	2.300	2.000	1.900	1.900	2.300	2.700	2.300	2.700	2.000	2.000	5.000	5.000
Maximum	4.300	4.900	4.400	4.600	4.700	4.700	4.700	4.700	10.00	10.00	10.00	10.00
Sum	175.0	179.4	180.3	198.8	186.7	195.7	193.3	203.4	291.0	309.0	409.0	410.0

The results show a systematic increase from pre-test to post-test for all three dimensions, illustrated in Fig. 15: metacognition increased by 3.0% in boys and 10.8% in girls, attitude toward physics by 3.5% in boys and 3.9% in girls, and academic success — the strongest effect — by 40.5% in boys and 32.7% in girls.

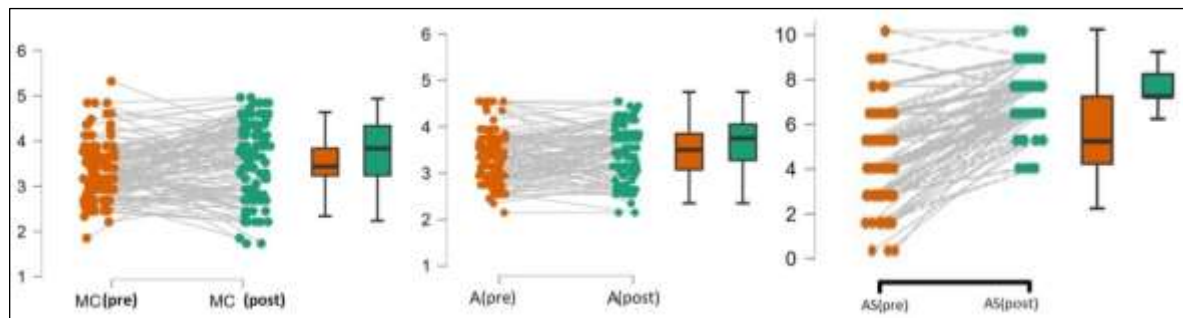


Figure 15. Pre-test and post-test results for metacognition, attitude, and academic success.

Fig. 16 confirms the non-Gaussian character of the distributions for all three dimensions, justifying the statistical tests used.

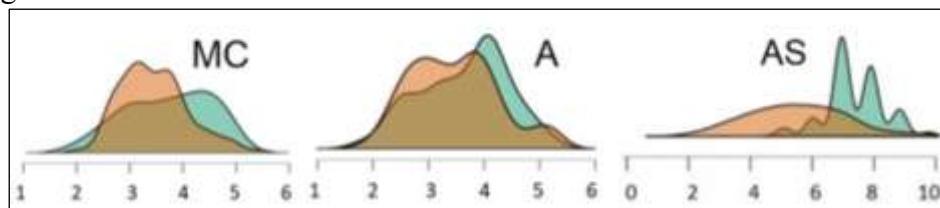


Figure 16. The non-Gaussian nature of the distribution curves for metacognition, attitude, and academic success. (brown – pre-test; green – post-test)

The paired-samples t-test (Table 16) shows significant pre/post differences for academic success ($p < 0.001$) and for the metacognitive and axiological dimensions ($p < 0.005$), with a very large effect size for academic success ($ES = 0.778\text{--}0.789$) and a moderate one for metacognition and attitude ($ES \approx 0.21\text{--}0.30$), thus confirming the first two research hypotheses (H1 partially, H2 fully).

Table 16. Paired-samples t-test

Pre-test		Post-test	Test	Statistic	z	df	p	ES	SE (ES)
Metacognition	–	Metacognition	Student	3.130			0.001	0.298	0.117
			Wilcoxon	3696.0	2.920	109	0.002	0.328	0.112
Attitude	–	Attitude	Student	2.213			0.014	0.211	0.106
			Wilcoxon	3087.0	2.557	109	0.005	0.299	0.116
Academic success	–	Academic success	Student	8.276			<0.001	0.789	0.121
			Wilcoxon	3640.0	6.408	109	<0.001	0.778	0.121

The impact on scientific competence, structured into five sub-components (DEFINITION, UNITS, FORMULA, SITUATIONS, LANGUAGE), is documented in Table 17: the largest increases were recorded in solving problem-situations (from 33 to 70 students) and in the use of scientific language (from 22 to 60 students), partially confirming hypothesis H3, the impact on UNITS being limited by an initial saturation effect (approximately 90 of 110 students already mastered this knowledge at pre-test).

Table 17. Descriptive statistics for the components of Scientific Competence

	DEFINITIONS		UNITS		FORMULAS		SITUATIONS		LANGUAGE	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Valid	110	110	110	110	110	110	110	110	110	110
Sum	33	40	88	90	55	58	33	70	22	60
Shapiro-Wilk	0.575	0.609	0.490	0.469	0.636	0.635	0.575	0.609	0.490	0.633
p-value	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001

The internal consistency of the instrument, presented in Table 18 through Cronbach's α coefficients between 0.70 and 0.90, confirms the reliability of the assessment model with five components.

Table 18. Reliability statistics for the components of Scientific Competence

		DEFINITIONS	UNITS	FORMULAS	SITUATIONS	LANGUAGE
Cronbach's α	Pre-test	0.760	0.903	0.850	0.760	0.813
	Post-test	0.830	0.906	0.802	0.824	0.786
Item-rest correlation	Pre-test	0.892	0.306	0.586	0.892	0.720
	Post-test	0.706	0.333	0.804	0.725	0.860

Subchapter 3.1 concludes by noting the overall effect size of PI (0.78–0.79), compared to that of traditional teaching (≈ 0.40), concluding that PI functions as an effective didactic mechanism, capable of simultaneously activating the cognitive, metacognitive, and axiological dimensions of LLLC.

Subchapter 3.2 begins with a diagnosis of the starting level: a questionnaire applied to 44 seventh-grade students from the "Vasile Badiu" (Măgurele) and "Anatol Popovici" (Boghenii Noi) middle schools, at the beginning of the school year, targeting understanding of basic sixth-grade concepts, application skills, interest in problem-situations, and attitude toward ICT. The results show a contrasting picture: only 47.7% of students are familiar with the concept of mass and 29.5% with that of density, 56.8% do not know that a molecule is composed of atoms, and only 20.2% correctly represent a beam of parallel rays, but 84% correctly identify the definition of lightning, and 70-86% know the units of measurement for weight, mass, area, and volume. Only 19% know what a dynamometer is and how to use it. On the problem-question about the ice cube floating in a glass full of water, almost 95% of students show at least moderate interest, a potentially untapped resource for learning through inquiry. Regarding ICT use, 59.1% rarely use electronic communication in learning, but over 90% would like the integration of digital tools, and 47.7% envision a career related to technology — a clear gap between attitude and actual practice, attributed to social and economic factors specific to the rural environment.

The second part of 3.2 theoretically grounds the role of conceptual questions (CQ) in the formation of LLLC: deep learning requires the confrontation and revision of pre-existing mental models through deliberate cognitive conflict, requiring the simultaneous integration of declarative, conditional, and procedural knowledge for understanding to become transferable. The author's own model *Learning by Being* is introduced, centered on the student taking ownership of their own cognitive objectives and on the integration of BSIs. Conditional knowledge is identified in the literature as the strongest predictor of conceptual understanding, and research on PI shows that it contributes to students' confidence in their own reasoning, to collaborative reasoning, and to reflective thinking — all defining components of LLLC.

The third part of 3.2 presents the subchapter's central experiment: four 8th-grade classes (57 students in the experimental group, 53 in the control group), with a final test of six items proportionally distributed across declarative (43.75%), conditional (40.63%), and procedural (15.62%) knowledge, applied after a sequence of six lessons: lesson 1 (teaching BSIs through CQ), lessons 2-3 (guided laboratories on Ohm's Law), lessons 4-5 (solving complex problems explicitly linked to a BSI each), lesson 6 (common summative test). In the experimental group, six CQs were integrated through the Turning Point platform, with two rounds of voting and discussion in pairs between rounds; the control group received traditional instruction, without explicit BSIs or CQs.

The results in Table 19 show a clear difference: the mode of the grades was 10 in the experimental group versus 6 in the control group, with means of 7.37 versus 5.98 (a difference of 23.2%) and medians of 8.0 versus 6.0.

Table 19. Descriptive statistics for the summative assessment results in the experimental and control groups.

	Grade	
	Experimental	Control
Number of students	57	53
Mode	10.000	6.000
Median	8.000	6.000
Mean	7.368	5.981
Std. Deviation	2.225	2.144
Skewness	-0.585	0.013
Std. Error of Skewness	0.316	0.327
Shapiro-Wilk test	0.918	0.957
P-value of Shapiro-Wilk	< .001	0.052
Minimum	1.000	2.000
Maximum	10.000	10.000

The distributions (Fig. 17–18, kernel density estimates) confirm the negative skewness (skewness = -0.585) in the experimental group — a concentration toward high grades — compared to an almost symmetric distribution (skewness = 0.013) in the control group.

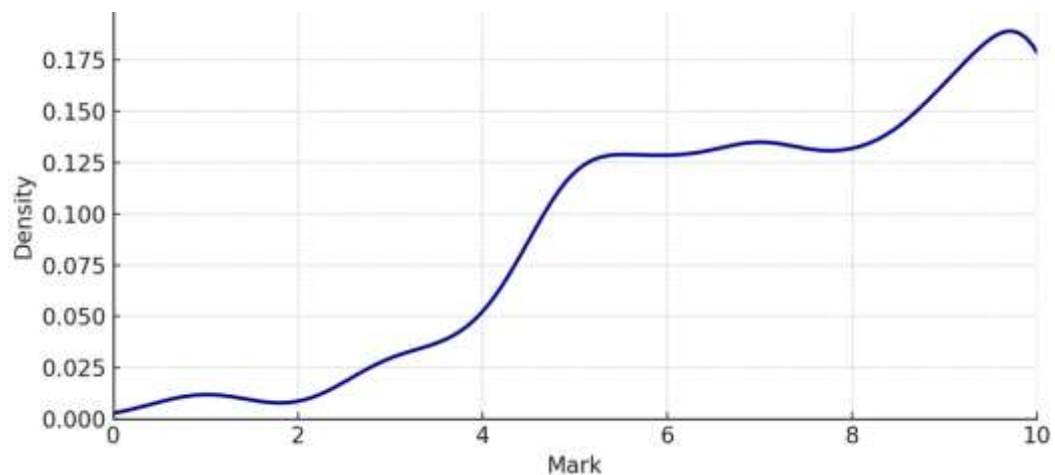


Fig. 17. Density estimate of post-test grades in the experimental group ($n = 57$).

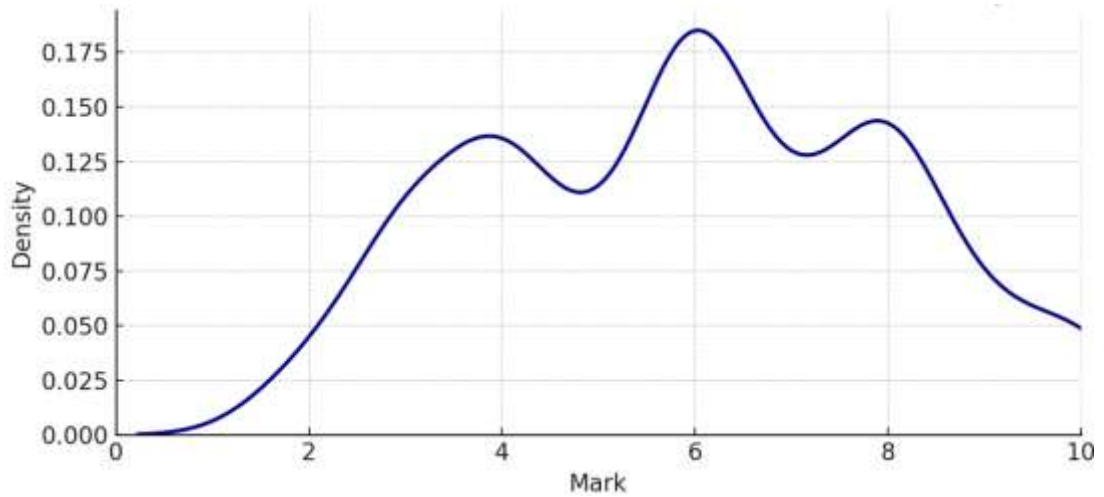


Fig. 18. Density estimate of post-test grades in the control group ($n = 53$).

Table 20 presents the Pearson and Spearman correlations between the grade and the three types of knowledge: declarative and conditional knowledge correlate very strongly with the grade ($r > 0.89$ in both groups), with Fisher's z effect sizes of 1.4–1.6, while procedural knowledge shows a moderate correlation ($r \approx 0.58$ –0.64) — and the experimental group shows better integration between the conceptual and the procedural, attributed to the didactic emphasis on “when” and “why”, not only on “how”.

Table 20. Pearson and Spearman correlations between final grades and students’ declarative, conditional, and procedural knowledge in the experimental and control groups.

	Both groups			Experimental Group			Control Group		
	Knowledge			Knowledge			Knowledge		
	Decl.	Cond.	Proced.	Decl.	Cond.	Proced.	Decl.	Cond.	Proced.
Pearson's r	0.894	0.898	0.620	0.902	0.905	0.635	0.887	0.923	0.582
p-value	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Effect size (Fisher's z)	1.440	1.460	0.725	1.480	1.498	0.750	1.409	1.608	0.666
Std. Err. for effect size	0.097	0.097	0.097	0.136	0.136	0.136	0.141	0.143	0.141
Spearman's ρ	0.890	0.911	0.640	0.868	0.917	0.602	0.888	0.947	0.581
p-value	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Effect size (Fisher's z)	1.422	1.532	0.758	1.326	1.569	0.696	1.414	1.806	0.664
Std. Err. for effect size	0.107	0.108	0.102	0.148	0.150	0.142	0.154	0.160	0.147

Table 21 presents the paired-samples t-test: the experimental group records a significant average gain (from 6.47 to 7.37; $d = 0.534$), while the control group remains practically unchanged ($d = 0.044$).

Table 21. Comparison of pre- and post-test results and effect size in the Experimental and Control groups in Electrokinetics

Group		N	Mean	SD	SE	Coef. of variation	t	p	Cohen's d	SE Cohen's d
Experimental	Pre-Test	57	6.474	1.428	0.189	0.221	4.030	1.000	0.534	0.117
	Post-test	57	7.368	2.225	0.295	0.302				
Control	Pre-Test	53	6.057	1.646	0.226	0.272	0.318	0.752	0.044	0.121
	Post-test	53	5.981	2.144	0.294	0.358				

Note: The alternative hypothesis assumes that the post-test is greater than the pre-test.

Subchapter 3.3 represents the integrative synthesis of the thesis: starting from the observation that traditional physics teaching, centered on content transmission, is no longer sufficient to meet current educational requirements, a multidimensional pedagogical model is proposed that articulates four axes: Cognition, Educational Methodology, Competences, and Disciplinary Complexity, each progressing through four of its own evolutionary stages, resulting in a total of 16 elements to be considered in didactic design oriented toward the formation of LLLC.

The Cognitive Progression Axis, with the stages *Knowledge – Understanding – Synthesis – Critical Evaluation*, describes the student's transition from factual knowledge to critical thinking, the teacher's role being to build mental schemas for organizing and analyzing information. A relevant empirical result is cited: approximately 90% of students acquire basic knowledge, but only 33% can plan a simple experiment and fewer than 20% can translate a situation into formulas or graphs, which justifies differentiated cognitive objectives in the classroom.

The Educational Methodologies Axis, with the stages *Technique – Method – Strategy – Paradigm*, draws on the principle of layering several effective didactic strategies, which generates a synergy effect, the concept being linked to the *Learning by Being* model. Each level is illustrated on the topic "Rectilinear Motion": *the technique* — manually timing an object over a fixed distance; *the method* — experimentally investigating the speed–distance–time relationship; *the strategy* — designing one's own experiment on the effect of a constant force;

the paradigm — the constructivist approach, which integrates mathematics and technology into the design of an energy-efficient vehicle.

The Competence Development Axis, with the stages *Exploration – Consolidation – Adaptation – Innovation*, follows, again using the example of rectilinear motion, the transition from the intuitive introduction of BSIs (the exploration stage), through the consolidation of concepts and of distance-time/speed-time graphical representations (the consolidation stage), to the transfer of knowledge into a new context, motion on an inclined plane with additional forces (the adaptation stage) and, finally, to the creative design of vehicle models from recyclable materials, a stage the author calls *Applied Physics Modelling* (the innovation stage).

The Disciplinary Complexity Axis comprises four stages: intradisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary. It examines the same topic from the perspective of knowledge integration, progressing from the relationships between displacement, velocity, acceleration, and time within physics, through connections with mathematics in the graphical analysis of motion, guided by Redish's principles of "Respect and Reflexive Design" [65], to transdisciplinary projects that extend beyond school subjects and draw on the transversal nature of learning-to-learn competence.

Subchapter 3.3 concludes by emphasizing that the four axes are complementary, each necessary but insufficient in the absence of the others, and the application of the 4D model to the topic "Rectilinear Motion" has an illustrative and exploratory character, demonstrating the feasibility and operational consistency of the model as an integrative tool for cognitive progress, didactic strategies, and the epistemic specificity of physics in the formation of LLLC.

The main results of Chapter III are described in the following papers by the author [14] "*Assessment of lifelong learning skills formed in the 6th grade physics course*", [16] "*Correlation Between Metacognition, Attitude and Academic Success in 7th Grade Physics Course*", [25] "*The 4-dimensional pedagogical model for the development of lifelong learning competences and its application to the study of rectilinear motion*", [20] "*Structural Knowledge Gains in Physics through Conceptual Questions and Peer Instruction*", [21] "*The Effects of Conceptual Questions on the Structure of Scientific Competence in 7th Grade Physics*", [26] "*Redefining physics in the era of competences: the pillar of forming lifelong learning competences*".

GENERAL CONCLUSIONS AND RECOMMENDATIONS

General conclusions

1. The analysis of the specialized literature and of educational policy documents has made it possible to clarify the evolution of the concept of competence, highlighting the move beyond the reductive perspective centered exclusively on the accumulation of knowledge and the shaping of a complex understanding, in which knowledge, skills, attitudes, and values are integrated and contextually activated. Lifelong learning competences stand out as a transversal construct, explicitly present in European and international reference frameworks, being associated with the individual's capacity to learn autonomously, to communicate effectively, and to apply knowledge in new situations.
2. Although the specialized literature indicates broad consensus on the importance of LLLC as a major educational outcome, the critical analysis has revealed that the concrete didactic mechanisms through which they can be systematically formed within school disciplines remain insufficiently clarified. The epistemic specificity of physics thus emerges as a privileged framework for investigation, through the discipline's capacity to integrate conceptual understanding, the application of knowledge, and reflection on one's own learning process.
3. The analysis of the theoretical framework of LLLC has made it possible to highlight the structural relationship between key competences and the didactic strategies used in teaching physics, showing that the formation of these competences is not a side effect of didactic activity, but the result of an intentional pedagogical approach, in which constructivist-oriented strategies activate cognitive effort, student engagement, and motivation for learning.
4. The analysis of learning through inquiry has made it possible to clarify its status as a pedagogical paradigm relevant to the formation of LLLC in the teaching of physics, the IBSE method being analyzed as a framework for organizing learning oriented toward conceptual understanding, through guided learning effort, the use of big scientific ideas, and the cyclical structuring of activities.
5. The examination of the role of big scientific ideas has highlighted their function as structuring elements of learning through inquiry and as conceptual links in the transition from mechanical memorization to learning through understanding, BSIs being interpretable as cognitive objectives and competence units, organized into a coherent conceptual chain.
6. It has been shown that the formation of LLLC in the physics lesson cannot be achieved through the extensive accumulation of content, but requires the reconfiguration of the didactic approach around the integrated development of knowledge, skills, and attitudes, through the

operationalization of learning through inquiry by means of IBSE and the redefinition of the teacher's role as a mediator of learning.

7. The concept of Didactic Synergy was formulated, based on the functional integration of several didactic models and strategies (reflective activities, problem-based learning, self-assessment, digital environments, experimental scenarios) into a unified approach, oriented toward cognitive activation and the self-regulation of learning, with an epistemic criterion for selecting strategies based on their impact on learning.

8. It has been demonstrated that the effectiveness of integrated didactic strategies is conditioned by the existence of a clear conceptual core, represented by big scientific ideas, formulated as cognitive objectives and competence units, capable of organizing the lesson around a limited number of fundamental concepts (usually three to four per lesson), facilitating the transfer of knowledge.

9. It has been empirically demonstrated that students' level of conceptual understanding is closely associated with the clarity with which big scientific ideas are introduced, consolidated, and assessed, the clear definition of BSIs, supported by permanent formative assessment, constituting the basic condition for authentic cognitive progress and for the formation of LLLC.

10. It has been shown that students' progress in physics is explainable through the systemic interaction between the theoretical, axiological, and metacognitive dimensions of knowledge, the transition from factual knowledge to metacognitive reflection not being a linear process, but dependent on the successive activation of higher levels of understanding, with an explicit operational role for the teacher in facilitating this progress.

11. It has been demonstrated, based on empirical data collected from a sample of 110 students, that the axiological and metacognitive dimensions are significantly associated with academic performance in physics, supporting their relevance to the formation of LLLC, highlighting stable positive relationships between metacognition, attitude, and academic success.

12. The triadic structure of scientific knowledge (declarative, procedural, conditional) was identified and operationalized, demonstrating the differentiated role of the types of knowledge in supporting academic success (Pearson correlations $r > 0.89$ for declarative and conditional knowledge) and the central role of conditional knowledge as a predictor of academic performance.

13. Through a pre-test/post-test design applied to 110 students, the impact of peer instruction combined with conceptual questions on metacognition, attitude, and academic success was

measured, obtaining statistically significant increases for all three dimensions, with high internal consistency of the assessment instruments (Cronbach's $\alpha = 0.76\text{--}0.91$).

14. The 4D Pedagogical Model for the formation of LLLC in physics lessons was developed, as an integrative synthesis of the theoretical and empirical results of the research, structured on four complementary axes — cognitive progress, didactic methodology, the development of learning competences, and disciplinary complexity — whose applicability was demonstrated through its operationalization on the topic “Rectilinear Motion”.

Recommendations

At the level of the Ministry of Education and Research:

- Clarifying and strengthening the status of lifelong learning competences as an explicit transversal outcome of the physics curriculum, by correlating existing national curricular documents with the concrete didactic mechanisms for forming LLLC at the level of the discipline.
- Developing a national methodological framework for teaching physics oriented toward the formation of LLLC, which should include guidelines on lesson design, the role of formative assessment, the use of feedback, and the integration of metacognitive and axiological dimensions into the teaching–learning–assessment process.

At the level of research institutions:

- Expanding and diversifying didactic research on the formation of LLLC in the teaching of physics, by investigating complementary dimensions — motivational dynamics, long-term self-regulation, interdisciplinary transfer, and the sustainability of the competences formed.

At the level of higher education institutions – initial training:

- Integrating the formation of LLLC into initial training programs for physics teachers, by developing didactic design competences oriented toward learning through understanding, metacognition, and conceptual transfer.

At the level of higher education institutions – continuing training:

- Orienting continuing teacher training programs toward developing the competence to select and use didactic strategies with scientifically demonstrated effectiveness, so that teachers can build varied, integrated didactic approaches adapted to the formation of LLLC.

At the level of educational institutions (schools):

- Adopting coherent internal policies to support the formation of LLLC, ensuring continuity and coherence between teaching, learning, and assessment, as well as institutional support for feedback mechanisms, reflection, and monitoring of student progress.

- Systematically using data on student progress to monitor the development of LLLC, through formative instruments that allow the regulation of the didactic process and the adaptation of educational interventions at the individual and group level.

At the level of methodological committees:

- Developing and using a common framework for analyzing the lesson and the didactic process, centered on explicit criteria oriented toward the formation of LLLC, with a view to identifying, validating, and disseminating effective didactic practices.
- Making use of methodological analyses to identify and disseminate didactic practices that contribute to the development of LLLC within physics lessons.

At the level of the teacher:

- Grounding the didactic approach in the principle of didactic synergy, through the functional layering of teaching, assessment, and feedback strategies, so that cognitive activation, metacognitive reflection, and the formation of attitudes toward learning simultaneously contribute to the development of lifelong learning competences.

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ANNOTATION

Dabija Viorel

The Formation of Lifelong Learning Competences within the Physics Lesson

Doctoral thesis in educational sciences, Chişinău, 2026

Structure of the thesis: the thesis consists of an introduction, three chapters, general conclusions and recommendations, a bibliography of 256 sources, an annotation (Romanian, English, Russian), keywords, and a list of abbreviations. The thesis comprises 147 pages of main text, with 23 figures, 28 tables, and 20 annexes. The results obtained are published in 13 scientific papers.

Keywords: lifelong learning competences, big scientific ideas, conceptual questions, science learning through the inquiry method, components of scientific knowledge, pedagogical model for the formation of learning competences.

The aim of the research consists in the theoretical grounding, the analysis of the cognitive mechanisms, and the experimental validation of the formation of lifelong learning competences in the teaching of physics.

The objectives of the research: (1) analyzing the conceptual and epistemic framework of lifelong learning competences and their status in the teaching of physics; (2) highlighting the role of big scientific ideas and conceptual questions in structuring learning through understanding and in the formation of learning competences; (3) explaining the mechanisms of the formation of lifelong learning competences; (4) experimentally investigating the impact of the peer instruction method on conceptual understanding, metacognition, attitude toward physics, and students' academic success; (5) developing and grounding the pedagogical model for the formation of lifelong learning competences in the teaching of physics.

The scientific novelty and originality consist in: correlating the conceptual framework of lifelong learning competences with the cognitive mechanisms of learning; treating big scientific ideas and conceptual questions as defining elements of the understanding of physics; analyzing the general construct of scientific knowledge; researching the impact of peer instruction on the triad of knowledge and on students' academic success; integrating cognition and didactic methodology into a unified pedagogical model for the formation of learning competences in the teaching of physics.

The result obtained solves the problem of clarifying the didactic mechanisms through which lifelong learning competences can be systematically formed in the teaching of physics.

The theoretical significance of the research consists in delimiting the conceptual framework of learning competences as a transversal educational outcome in the teaching of physics, explaining the relationships between big scientific ideas, the components of scientific knowledge, and the cognitive mechanisms of learning, as well as the empirical validation of the relationships between conceptual understanding, metacognition, attitude toward physics, and academic success, integrated into an explanatory pedagogical model.

The practical value of the work consists in providing an operational pedagogical framework for the formation of lifelong learning competences in the teaching of physics.

The implementation of the scientific results was carried out within the pedagogical experiment conducted at the IPLT "M. Eminescu" in the municipality of Ungheni, at the republican methodological seminars for physics teachers, as well as at national and international conferences.

DABIJA VIOREL

**THE FORMATION OF LIFELONG LEARNING COMPETENCES
WITHIN THE PHYSICS LESSON**

532.02 School Didactics (Physics)

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