Application of Combined Constructivist Strategies in Physics Teaching

Identifying the most effective teaching strategies for physics instruction is a persistent challenge for both researchers and schoolteachers. Studies indicate that the answer lies in Research-Based Instructional Strategies. A significant contribution in this area has been made by the theory of Visible Teaching and Learning, which measures the effects of over 250 factors influencing students' academic success. By knowing the possible impact of specific teaching strategies, educators can design instructional approaches with predictable outcomes. The research was conducted during the 2023-2024 academic year in two public schools in Moldova, involving 305 students across grades 6, 8, and 10. This study aimed to measure the effect of concurrently applying elements from multiple constructivist teaching strategies in physics lessons, including the Flipped Classroom, Early Physics Approach, 5E Model, and Peer Instruction with Conceptual Questions, on students' academic success and science competence in physics. At its core, the study was based on the 5E model, reinforced with pre-class tasks for students and the use of conceptual questions during the lesson. Science competence of students was structured into five components: understanding definitions, knowledge of measurement units, correct application of formulas, problem-solving skills, and the use of scientific language. The progression of these components was subsequently measured. The study also tracked the individual academic trajectories of both high-performing and low-performing students to assess their progress in physics. The study revealed that the combined application of these constructivist strategies can double students' ability to solve problem situations and triple the correct use of scientific language. In contrast, knowledge of measurement units (~80%) and the correct application of formulas (in the range of approx. 25% – 33%) remained relatively unchanged. The insignificant progress in the correct application of formulas is explained by the small number of problems analysed on a topic, the lack of individual tasks, and the need for more explicit scaffolding and individual feedback. Additionally, the study revealed that laboratory work marks are strong predictors of overall academic success, with the correlation between laboratory work and final evaluation being 60% in 6th grade, 70% in 8th grade, and 50% in 10th grade. Additionally, the research shows that in middle school, the increase in scores for high achievers is greater than that of low achievers — three times higher in 6th grade. In high school, the increase in scores for high achievers is twice as large as that of low achievers. Both groups, high and low achievers, improve their scores after the application of the Integrated Constructivist Model. Subsequent research would explore the synergistic effect of this, and other, combinations of constructivist teaching strategies on students' academic success, scientific competence components, and conceptual understanding.

Keywords: *Integrated constructivist model, didactic synergy, science competence, academic success, physics teaching.*

Introduction

Traditional expository teaching methods limit student success and interest in physics, especially when it is perceived as a difficult subject (Bologna et al., 2024; Guisasola, 2019; Zhou, 2004). Interactive strategies based on active knowledge construction stimulate curiosity and active participation, thus improving students' attitudes toward science.

Teaching strategies are a factor that influences intrinsic motivation. Certain teaching approaches focused on facilitation and communication can have positive effects on intrinsic motivation components (Bonnia et al., 1997; Hansson et al., 2023; Hattie, 2009). At the same time, relatively rigid learning environments do not favor the application of motivational strategies, such as fostering group cohesion among students or strengthening the teacher-student relationship (Guilloteaux & Dörnyei, 2008; McNeil, 2018). When designing an instructional approach aimed at fostering motivation, we can rely on five principles proposed by Linnenbrink-Garcia et al. (2016):

1. Competence is fostered by well-designed instruction, cognitively challenging tasks, and ongoing mutual feedback.
2. Student autonomy is encouraged by providing opportunities for decision-making and careful guidance.
3. Physics identity and active student engagement are promoted through personalized, relevant, and interesting tasks.
4. Emphasizing learning and understanding rather than performance and competition.
5. Supporting group cohesion by fostering feelings of belonging and relationships between students and teachers.

These principles emphasize the importance of instructional design that nurtures both cognitive and emotional aspects of learning, ultimately fostering a deeper and more sustained commitment to physics. Moreover, research indicates that effective teacher practices aimed at enhancing student motivation are largely consistent with these theoretical principles, suggesting that school practice generally adheres to Research-Based Instructional Strategies (RBIS) (Radil et al., 2023; Schell & Butler, 2018).

Physics is a discipline based on fundamental concepts, and rote learning of formulas and definitions without deep understanding leads to difficulties in applying knowledge to new situations. Identifying effective teaching strategies contributes to developing critical thinking and solid conceptual comprehension.

A constructivist teaching strategy cannot be built within the paradigm of traditional, lecture-based instruction that relies on memorization. Simply providing students with definitions of concepts does not help them integrate new information into their knowledge and value system (Brafman, 2003; Freeman et al., 2014). For example, mere note-taking of the teacher's statements is less effective for retention compared to developing cue signals or concept maps (Iofciu et al., 2011; Pals, 2017). Establishing connections between abstract concepts and concrete situations through recurrent priming appears to be a solution for improving conceptual understanding (Johnstone, 2000).

Strategies such as the open inquiry learning model positively affect conceptual understanding and attitudes (Arra, 2021). The Flipped Classroom method significantly enhances (effect size of 0.953) comprehension of basic scientific concepts (Ugwuanyi, 2022), while the Peer Instruction method yields various positive learning outcomes, such as deeper conceptual understanding, improved problem-solving skills, and increased student engagement (Crouch et al., 2007; Schell & Butler, 2018). Multiple studies have shown that the constructivist 5E model improves science learning outcomes for students of different ages, with an effect size of 0.82 when implemented instead of traditional instruction methods, such as direct instruction, lectures, or traditional lab work (Polanin, 2024).

At the same time, research indicates that misconceptions persist among school students, university students, and even teachers, regardless of whether instruction follows traditional or constructivist approaches. This suggests that the key factor in addressing misconceptions is not merely the teaching strategy itself but the explicit effort to correct prior misunderstandings rather than simply striving for higher grades (Müge & Hacıoğlu, 2022).

Following this idea, effective physics instruction must incorporate core principles that enhance conceptual understanding and engagement. According to Bonacci (2020), six essential requirements for teaching physics can guide the design of instructional strategies:

1. Appealing epistemological richness
2. Interdisciplinary study
3. Curiosity about basic notions
4. Compact formulation of fundamental ideas
5. Unifying logic of explanations
6. Captivating narration

Physics is not just about accumulating information; it is a discipline that develops essential competencies such as problem-solving, logical reasoning, and the use of scientific language. In physics lessons, the focus is not merely on transmitting information but on acquiring knowledge structured on two levels:

- Factual knowledge – understanding facts and their physical meaning.
- Procedural knowledge – applying and integrating knowledge.

The term “acquisition” itself points to the cognitive effort students must make as a prerequisite for effective learning (Calalb, 2023). This effort is shaped by individual starting points, as research shows that while the assimilation mechanisms of high-achieving and lower-achieving students are fundamentally the same, differences arise from their prior knowledge and initial level of understanding at which learning begins (Binder et al., 2019).

Prior knowledge forms the basis of strategies such as retrieval practice, which positively influences problem-solving skills (Gjerde et al., 2022). Teaching strategies influence problem-solving, but equally important is how the problem is presented by the teacher—whether verbally, pictorially, or graphically (De Cock, 2012). This highlights the importance of training students to analyse problem situations using multiple approaches. Effective teaching strategies should support the development of these competencies, preparing students for complex academic and professional contexts.

Physics laboratory activities, when designed based on constructivist principles and focusing on competence development rather than mere content retention, enhance students' critical thinking skills (Walsh et al., 2022). Physics lessons are particularly suitable for fostering critical thinking, as scientific reasoning, which is continuously exercised in physics classrooms and laboratories, is symbiotically linked to critical thinking (García-Carmona, 2023).

In a heterogeneous classroom, some students progress quickly while others struggle. Well-chosen teaching strategies enable personalized learning, providing support for struggling students and appropriate challenges for advanced students, thereby reducing educational inequalities.

Developing teaching methods that consider students' initial knowledge levels and incorporate active learning strategies helps bridge performance gaps and ensures progress for all students (Salehi et al., 2019). Research indicates that the effect size of instructional strategy clusters on physics achievement is approximately 0.73 (Sezgin Selçuk, 2010). Teaching strategies based on research, combined with PhET simulations, significantly improve students' conceptual understanding and help them overcome alternative conceptions (Quezada-Espinoza et al., 2015).

The SCALE-UP model, as an RBIS one, emphasizes active learning and student engagement, aligning instructional approaches with student needs (Scanlon et al., 2019). The effectiveness of RBIS lesson sequences is determined by three key factors: cognitive scaffolding, feedback-based methodology, and the presence of student-led inquiry or IBSE (Inquiry-Based Science Education) in the classroom (Guisasola, 2019).

RBIS strategies have been rigorously tested in various educational contexts, demonstrating their impact on student learning (Hattie, 2009). This reduces uncertainty and increases the likelihood of positive outcomes when using teaching methods focused on active student learning and experimental validation (Freeman et al., 2014).

Instructional strategies scientifically validated enhance students' conceptual understanding and their attitude toward science while allowing teachers to design lessons with more predictable outcomes, avoiding inefficient methods based solely on intuition or personal experience (Neri et al., 2011).

Research in Physics Education Research (PER) and Science Education examines teaching strategies across different levels, from primary school — where foundational understanding of natural phenomena and exploratory learning are emphasized (Makarskaite-Petkeviciene, 2023) — to high school, where the core concept in physics lesson design becomes Visible Teaching and Learning, increasing student achievement through constructivist strategies (Tong et al., 2023).

RBIS frameworks highlight four categories of variables that influence physics learning: prior domain-specific knowledge, auxiliary prior knowledge, past academic achievements or skills, and metacognition and motivation (Delahay et al., 2023). However, further quantification and operationalization of RBIS and constructivist frameworks are needed to facilitate their classroom implementation (Radicuks et al., 2025).

Thus, identifying the most effective strategies for teaching physics is crucial for enhancing student engagement and conceptual understanding. Approaches such as Flipped Classroom, Peer Instruction, IBSE, and Early Physics Approach offer significant potential for improving learning outcomes. The following section will explore the theoretical foundations that support the integration of these constructivist strategies into a unified pedagogical approach, emphasizing their synergistic effect in physics education.

Theoretical Framework

The methodologies in PER are "delightfully unsettled" and, in the pursuit of improving physics teaching and understanding, integrate pedagogy, cognitive sciences, and educational theories (Hammer, 2023; Docktor, 2024). Since critical thinking and creativity are key vehicles for achieving conceptual understanding in physics learning, teaching methods should adapt to foster these two components of constructivist learning. In order to effectively stimulate critical thinking and creativity, teaching strategies are expected to align with constructivist principles. This requires adopting innovative instructional approaches that encourage student engagement and ownership of their learning process (Calalb & Zelenschi, 2023; Rutto et al., 2023). Moreover, any constructivist teaching strategy in physics will emphasize the development of student motivation and engagement (Linnenbrink-Garcia et al., 2016; Radil et al., 2023), as motivation and engagement lead to greater involvement, promote self-directed learning, and ultimately enhance academic performance (Kazakova et al., 2022).

From the broad spectrum of RBSE constructivist strategies, we will briefly describe those that formed the foundation of our experiment. First, we consider the Flipped Classroom concept, introduced by J. Wesley Baker and further developed in the early 2000s by Bergmann & Sams (2012)**,** who recorded their chemistry lessons for students to watch at home. In physics lessons, the Flipped Classroom is widely applied within the Peer Instruction method developed by E. Mazur (Crouch et al., 2007), where students read the lesson material in advance and respond to a set of control questions. This approach supports the inclusion of students who struggle to concentrate during class, thus addressing individual differences **(**Eroğlu & Yüksel, 2020**).** Moreover, the Flipped Classroom does not fundamentally alter the traditional 5E instructional model; instead, it facilitates the implementation of the first two phases—Engagement and Explanation — and shifts the teacher's role toward facilitating peer discussions. As a result, the Flipped Classroom increases classroom interactions, thereby enhancing feedback, making both teaching and learning more visible (Calalb & Zelenschi, 2024**)**.

Secondly, we applied elements of Peer Instruction, which is an inherently constructivist strategy, as it actively engages students in the learning process through conceptual questions that require reasoning rather than mere memorization. Discussions among peers, as they analyse possible answers to these conceptual questions, facilitate conceptual understanding by helping students abandon their prior misconceptions (Miller et al., 2015), thereby resolving cognitive conflicts. The teacher, acting as a guide and facilitator, directs students' learning towards dialogue and collaboration. At the same time, Peer Instruction is also an RBIS method, as it is grounded in research on the difficulties students face in constructing conceptual understanding. Its effectiveness has been demonstrated by experimental studies showing significant improvements in conceptual comprehension (Stoen et al., 2020) and academic achievement, with an effect size of 0.92 (Hattie, 2009) — more than twice that of traditional or lecture-based teaching, which has an effect size of 0.40. Additionally, frequent formative assessment through conceptual questions ensures immediate feedback, aligning Peer Instruction with the principles of Visible Teaching and Learning.

Thirdly, the design of our pedagogical approach was based on the 5E model (Bybee et al., 2006), an active and constructivist learning method. In each of its five stages (Engagement, Exploration, Explanation, Elaboration, and Evaluation), students are encouraged to actively engage in the learning process, construct understanding through hands-on experiences, and apply concepts in new contexts (Polanin et al., 2024). In the Engagement stage, students are stimulated to connect prior knowledge with new concepts, while in Exploration, they investigate through experiments and practical activities, incorporating elements from Inquiry-Based Science Education. The Explanation stage focuses on clarifying and consolidating knowledge through discussions and reflections guided by the teacher. Furthermore, the 5E model ensures that feedback is continuous, immediate, and reciprocal throughout the lesson (Calalb, 2021). Thus, the 5E model fosters an iterative and interactive learning process that ultimately shapes students' attitudes and their physics identity. It is important to emphasize that the 5E model aligns with the RBIS, as it is supported by research showing significant improvements in students' scientific understanding and academic performance. For example, the effect size for academic success is 1.132, for retention 1.417, and for attitude 0.552 (Anil & Batdi, 2015).

The transition from traditional teaching to constructivist learning is further supported by the Early Physics Approach (Bologna et al., 2024), which addresses both teachers' understanding of students' learning difficulties — aligning with the principles of Visible Teaching and Learning — and the revision of Pedagogical Content Knowledge to better integrate mathematical reasoning into physics instruction. This integration is crucial, as mathematical reasoning enables students to grasp the physical meaning of learned concepts (Uhden et al., 2011). By strengthening algebraic thinking skills, Early Physics Approach facilitates the comprehension of physics concepts, allowing students to build flexible and well-conceptualized cognitive representations. Moreover, EPA fosters the development of an active scientific language in both physics and mathematics (Bologna et al., 2023), a particularly valuable aspect in an era of declining overall scientific literacy.

As seen, EPA is rooted in constructivist principles, as it combines multiple representations with scientific discourse, enabling students to articulate their reasoning scientifically and develop a critical understanding of newly acquired concepts. At the same time, since the theoretical foundation of the Early Physics Approach is based on educational frameworks such as ISLE (Investigative Science Learning Environment) (Etkina et al., 2021) and incorporates innovative methodologies and experimental tests validated by previous studies in Physics Education Research, it can be confidently classified as part of the RBSE (Research-Based Science Education) spectrum. EPA is particularly applicable in secondary education, especially in early middle school years, when students first encounter physics and require support in transitioning from fundamental mathematical concepts to physical principles.

The Concept of Didactic Synergy

The integration of elements from multiple teaching strategies within a single lesson to enhance learning efficiency has been explored in various studies within Physics Education Research (PER). For instance, in 1997 Eric Mazur demonstrated that combining Peer Instruction with the Flipped Classroom significantly improves students' conceptual understanding. Similarly, in 1998, Richard Hake showed that using Just-in-Time Teaching (JiTT) alongside ConcepTests leads to greater conceptual understanding compared to traditional teaching methods, with later research reporting a normalized learning gain of $g = 0.56$ (Hake, 1998).

More recently, Eugenia Etkina et al. (2021), building on the principles of Inquiry-Based Science Education (IBSE), developed the Investigative Science Learning Environment (ISLE) — an approach that fosters both critical thinking and student autonomy, with an effect size of 1.06 on students' attitudes toward physics (Brookes et al., 2020).

Thus, based on these examples, we can talk about the concept of Didactic Synergy when elements from different teaching strategies are used within the same lesson. For instance, in a student research-based learning project, we use Project-Based Learning, Problem-Based Learning, Inquiry-Based Science Education, Conceptual Questions, the 5E model, etc. The first step in applying Didactic Synergy is the sequential design of the lesson or teaching unit, where we can opt for a cyclical structure – an IBSE project, or a recurrent linear structure such as Reflective Practice. The following steps involve selecting strategies for a particular lesson sequence that align with the didactic goals and cognitive objectives of the lesson. Thus, Didactic Synergy is a holistic approach based on the teachers' PCK, their ability to use multiple teaching strategies, and it stems from the need to constantly motivate students and diversify activities in the learning process. It is worth noting that, according to Dewey, changing the type of activity stimulates a more efficient mental process. Therefore, through Didactic Synergy, active, dynamic, and interactive learning is achieved. Moreover, according to Vygotsky, to fully leverage the students' potential, i.e., to bring them into the zone of proximal development, challenges and experiences are necessary to expand their thinking and stimulate their interest in knowledge. According to Piaget, this shift in the range of activities contributes to students' assimilation of new knowledge and the adjustment of previous ones. Thus, the variety of teaching strategies applied within the same lesson facilitates cognitive development through a set of different activities based on interaction.

According to these considerations, we can assert that for Didactic Synergy to generate a cumulative effect that surpasses the effect size of its most effective individual component, it is advisable to adhere to the following three principles:

a) at least one of the employed teaching methods should foster cognitive activation;
b) one method should involve metacognitive inquiry;
c) one method should ensure the visibility of teaching and learning, meaning it should be feedback-based.

To exemplify how these principles translate into practice, Table 1 presents several instructional methods structured accordingly and categorized into teaching and learning methods. It can be observed that the most effective methods for activating cognition or cognitive effort of students are those classified as learning methods, where the teacher coordinates and guides students. In other words, while learner independence is valuable, it has its limits. High-quality learning, where students make meaningful progress in their knowledge, is impossible without teacher guidance. At the same time, the most effective metacognition-based methods are the learning ones and, according to Visible Learning (Hattie, 2009), have the highest effect sizes. However, methods such as Scaffolding or Summarization highlight the essential role of the teacher in directing students toward conceptual understanding. As expected, feedback-based methods cannot be strictly divided into learning or teaching methods, as genuine feedback is inherently mutual — the student and teacher engage equally in the process — in full alignment with the principles of Visible Teaching and Learning.

Table 1. *Didactic methods clustered by cognitive activation, metacognition, and feedback*

Type of method	**Learning method & effect size, ES**		**Teaching method, ES**	
Cognitive Activation	Reciprocal teaching	0.75	Cognitive task analysis	1.29
	Rehearsal and memorization	0.74	Jigsaw method	1.20
	Deep motivation and approach	0.69	Strategy to integrate with prior knowledge	0.93
	Field independence	0.68	Scaffolding	0.82
Metacognitive Inquiry	Self-report grades	1.44	Summarization	0.79
	Piagetian programs	1.28	Planning and prediction	0.76
	Help seeking	0.72	Evaluation and reflection	0.75
	Self-verbalization and self-questioning	0.55	Elaboration and organization	0.75

Feedback-based	Teacher estimates of achievement	1.29
	Response to intervention	1.29
	Transfer strategies	0.86
	Classroom discussion	0.82

In line with the concept of Didactic Synergy stated above, a single lesson can integrate essential elements from at least five methods: two for cognitive activation (one focused on learning, the other on teaching), two for metacognitive inquiry, and at least one feedback-based method. Thus, as an example, we can select the following:

For cognitive activation: as a teaching method, Cognitive Task Analysis (ES = 1.29), where the teacher helps students break down complex tasks to facilitate deeper learning; as a learning method, Reciprocal Teaching (ES = 0.75), which promotes active thinking through structured discussions among students.

For metacognitive inquiry: as a teaching method, Summarization (ES = 0.79), which supports students in identifying key ideas and organizing their knowledge; as a learning method, Piagetian Programs (ES = 1.28), which foster cognitive development through activities tailored to students' developmental stages.

For feedback: Classroom Discussion (ES = 0.82), which encourages bidirectional feedback and concept clarification through direct interaction.

Thus, by systematically selecting and applying such teaching methods, since it is crucial for students to fully master all the details and nuances of these methods to avoid wasting valuable lesson time, we can significantly enhance their academic success. The cumulative effect size remains to be demonstrated, but it is expected to exceed the highest ES of the individual components applied.

Research Objectives

The overall aim of this research was to assess how a combination of constructivist teaching strategies (Flipped Classroom, Early Physics Approach, 5E Model, Peer Instruction with Conceptual Questions) can be effectively implemented in physics lessons and to evaluate its impact on students' academic success and on scientific competence, which in this study is structured into five key components: understanding of definitions, knowledge of measurement units, correct application of formulas, problem-solving skills, and the use of scientific language. Additionally, we have examined how different student groups (high-performers and low-achievers) respond to this instructional approach.

Research Questions

RQ_1: How does the integration of constructivist teaching strategies in physics influence the academic success of students at different school levels?

RQ_2: What is the impact of the method on the components of students' scientific competence?

Research Hypotheses

H_1: The combined application of constructivist teaching strategies (Flipped Classroom, Early Physics Approach, 5E Model, Peer Instruction with Conceptual Questions) enhances the academic success of students and the components of their scientific competence in physics.
H_2: As a result of the combined application of constructivist teaching strategies, the improvement in academic success will be greater for high-performing students than for low-performing students.

Methodology

The experiment took place throughout the entire 2023-2024 academic year and was conducted in two public schools in the Republic of Moldova: "Mihai Eminescu" Theoretical High School in Ungheni and "Hyperion" Theoretical High School in Durlești. A total of 305 students from the 6th, 8th, and 10th grades participated. Apart from laboratory work and end-of-chapter evaluations, all lessons were conducted according to the Integrated Constructivist Model (ICM), presented in Table 2. IPM is based on the 5E model and implemented as follows: a) Flipped Classroom – where students independently familiarize themselves with the upcoming lesson topic at home by watching a 10–18-minute video on the educatieonline.md platform developed by Education Directorate of Chișinău (2021); b) Peer Instruction, involving 2-3 Conceptual Questions during the lesson; c) Early Physics Approach, emphasizing the understanding and scientific explanation of phenomena. We mention that group work of 4-5 students (Explore phase) and guided discussions are present in every lesson phase. Thus, the structure of the lesson is similar to that presented by M. Planinic et al. (2024), which contained the same distinctive elements of a constructivist lesson: guided discussions, interactive demonstrations, group work, and conceptual questions. In the final phase of the lesson, students complete an exit ticket with a question that summarizes what they have learned and stimulates metacognition. For example: "Today I understood that Ohm's Law helps us to..." or "A new thing I learned today is..." For the conceptual questions and exit ticket, anonymous digital assessment was used with the Turning Point clicker system.

Table 2. *Integrated Constructivist Model for a Physics Lesson*

Phase	Action
0	Flipped Classroom
1. Engage (7 min.)	Demonstration Conceptual question 1
2. Explore (8 min)	Early Physics Approach Demonstration Guided discussions and conclusions
3. Explain (15 min.) Peer Instruction	Explanation Conceptual question 2 Virtual experiment and conclusions
4. Elaboration (10 min)	Graph and table drawing of measurement data.

	Discussions and conclusions
5. Evaluation (5 min)	Exit ticket

Research Design

The study analyses the impact of applying the Integrated Constructivist Model on the academic success and scientific competence components of students. The experiment was conducted at three school levels: lower secondary – 6th grade (121 students), upper secondary – 8th grade (127 students), and high school – 10th grade (57 students). The main objective was to compare students' performance before and after applying the method, using quantitative indicators. The research is designed with a pre-test and post-test.

The analysed variables are the following:

1. Academic success (pre-test and post-test), noted as Evaluation Pre-test and Evaluation Post-test.
2. Marks from laboratory work (pre-test and post-test), noted as Lab Pre-test and Lab Post-test.
3. Evolution of scientific competence, analysed through five components:
    - Knowledge of definitions (pre-test and post-test), noted as Def Pre-test and Def Post-test.
    - Knowledge of measurement units (pre-test and post-test), noted as UM Pre-test and UM Post-test.
    - Proficiency in using learned formula for solving simple problems (pre-test and post-test), noted as Formula Pre-test and Formula Post-test.
    - Ability to solve problem situations (pre-test and post-test), noted as PS Pre-test and PS Post-test.
    - Capability to use fluently scientific language (pre-test and post-test), noted as SL Pre-test and SL Post-test.

For the description of academic success, marks from 1 to 10 from the final assessments of each chapter were used. Within each chapter, students perform at least one laboratory work, for which they are marked on a scale from 1 to 10. The five components of scientific knowledge were extracted from the analysis of specific assessment items in the final evaluations and were scored with 0 and 1.

Participants

In this pedagogical study, the participants were:

- lower secondary level (6th grade), 57 boys and 64 girls, aged 11–12 years
- upper secondary level (8th grade), 58 boys and 69 girls, aged 13–14 years
- high school level (10th grade), 23 boys and 34 girls, aged 15–16 years

All students came from a similar urban environment and shared a comparable socio-economic background, ensuring consistency in external factors that might influence academic performance.

Data Collection and Analysis

In Table 3, the results from the evaluations and laboratory work at the beginning and end of the experiment are shown. For the evaluations, we observe an increase of about 10%, while for the laboratory work, the increase is about 17%. The figures for standard deviation indicate that as a result of the intervention, there is greater variability in both the control and laboratory work results. The skewness values close to zero suggest a symmetric distribution of the marks. The Shapiro-Wilk values close to 1 indicate a normal distribution of the data. The Lab Pre-test and Lab Post-test have p-values which indicate that the data in these categories deviates slightly from normality but is still within an acceptable range for most analyses. Thus, the progress index shows a moderate effect of the ICM on the academic success of 6th-grade students (0.572) and a strong impact on performance in laboratory work (0.887).

Table 3. *Descriptive statistics of marks from final evaluations and laboratory work in 6th grade*

	Evaluation Pre-test	**Evaluation Post-test**	**Lab Pre-test**	**Lab Post-test**
Valid	121	121	121	121
Mean	6.458	7.092	6.126	7.183
Std. Deviation	1.108	1.227	1.191	1.295
Skewness	-0.122	-0.134	0.143	-0.107
Shapiro-Wilk	0.985	0.984	0.978	0.977
P-value	0.217	0.152	0.049	0.033
Progress Index	0.572		0.887	

In Table 4, the 8th-grade evaluation results show an 8.3% mean increase, while laboratory work marks improved by over 15.7%. Standard deviations indicate a slight rise in variability in post-tests. Skewness values remain close to zero, suggesting symmetric distributions. The Shapiro-Wilk test results confirm near-normal data distribution, with minor deviations that remain acceptable for analysis. Thus, the progress index shows a moderate effect of ICM on the academic success of 6th-grade students (0.611) and a strong impact on performance in laboratory work (0.921).

Table 4. *Descriptive statistics of marks from final evaluations and laboratory work in 8th grade*

	Evaluation Pre-test	**Evaluation Post-test**	**Lab Pre-test**	**Lab Post-test**
Valid	127	127	127	127
Mean	7.157	7.751	6.872	7.949
Std. Deviation	0.972	1.203	1.169	1.243
Skewness	0.005	-0.144	-0.027	-0.325
Shapiro-Wilk	0.989	0.979	0.981	0.970
P-value	0.416	0.050	0.071	0.006
Progress Index	0.611		0.921	

In Table 5, the 10th-grade results show an 8.9% increase in marks for final evaluations and a 14.1% rise in marks for laboratory works. Standard deviations indicate a slight rise in variability. Skewness values suggest higher-end scores, especially in laboratory tasks. The Shapiro-Wilk test confirms near-normal distribution, except for the Lab Pre-test, which deviates due to the small sample size and a higher number of students with high scores. Thus, the progress index shows a moderate effect of ICM on the academic success of 6th-grade students (0.563) and a strong impact on performance in laboratory work (0.816).

Table 5. *Descriptive statistics of marks from final evaluations and laboratory work in 10th grade*

	Evaluation Pre-test	**Evaluation Post-test**	**Lab Pre-test**	**Lab Post-test**
Valid	57	57	57	57
Mean	7.156	7.795	7.619	8.695
Std. Deviation	1.134	1.293	1.318	1.481
Skewness	0.134	0.203	0.900	0.816
Shapiro-Wilk	0.963	0.961	0.914	0.947
P-value	0.075	0.061	< .001	0.015
Progress Index	0.563		0.816	

Table 6 presents the correlation between the marks obtained in laboratory work and those from final evaluations for the 6th, 8th, and 10th grades, using two regression models:

- M_0 – the baseline model, corresponding to the null hypothesis, which assumes there is no relationship between laboratory marks and final evaluations.
- M_1 – the improved model, corresponding to the alternative hypothesis, which includes laboratory marks as a predictor for final evaluation marks.

It was found that the relationship between the marks for laboratory and those for final evaluations is significant in all grades, but stronger in the 8th grade (R = 0.882) and weaker in the 10th grade (R = 0.720). The 8th grade has the best prediction (Adjusted $R^2 = 0.775$, RMSE = 0.570), suggesting that laboratory marks are a better predictor for final evaluations at this age. In the 10th grade, the correlation is weaker, indicating that additional factors may influence the final evaluation marks (e.g., the difficulty of the subject).

Table 6. *Correlation between marks for laboratory works and final evaluations*

Grade	Model	R	R^2	Adjusted R^2	RMSE
6th	M_0	0.000	0.000	0.000	1.227
	M_1	0.778	0.605	0.602	0.774
8th	M_0	0.000	0.000	0.000	1.203
	M_1	0.882	0.777	0.775	0.570
10th	M_0	0.000	0.000	0.000	1.293
	M_1	0.720	0.519	0.510	0.905

In Table 7, the descriptive statistics for the final evaluation scores are presented for high achievers (H), i.e., those students who completed the academic year with scores above 9; medium achievers (M), who finished with scores between 7 and 8; and low achievers (L), whose scores were below 7. It is important to note that students who started the year with scores below 9 but ended with scores above 9 have been included in the category of high achievers, and similarly for the other groups.

In the 6th grade, the academic performance of high achievers increased by 13.2%, or 1.111 points, for medium achievers by 10.1%, or 0.697 points, and for low achievers by 8.1%, or 0.35 points. Thus, the increase in scores for high achievers in the 6th grade is three times greater than the increase for low achievers.

In the 8th grade, academic performance for high achievers increased by 9.8%, or 0.839 points, for medium achievers by 10.4%, or 0.749 points, and for low achievers by 0.8%.

In the 10th grade, academic performance for high achievers increased by 9.9%, or 0.882 points, for medium achievers by 8.5%, or 0.615 points, and for low achievers by 6.9%, or 0.4 points. Therefore, the increase in scores for high achievers in the 10th grade is double that of low achievers.

Table 7. *Descriptive statistics for high (H), medium (M) and low (L) achievers in 6th, 8th and 10th grades*

Grade		High		Medium		Low	
		Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
6th	Valid	9	9	68	68	44	44
	Median	8.300	9.500	6.800	7.400	5.600	5.950
	Mean	8.400	9.511	6.874	7.571	5.418	5.857
8th	Valid	23	23	72	72	32	32
	Median	8.500	9.300	7.050	7.800	6.100	6.150
	Mean	8.591	9.430	7.175	7.924	6.088	6.156

10th	Valid	11	11	32	32	14	14
	Median	8.800	9.900	7.200	7.750	5.750	6.300
	Mean	8.900	9.782	7.194	7.809	5.800	6.200

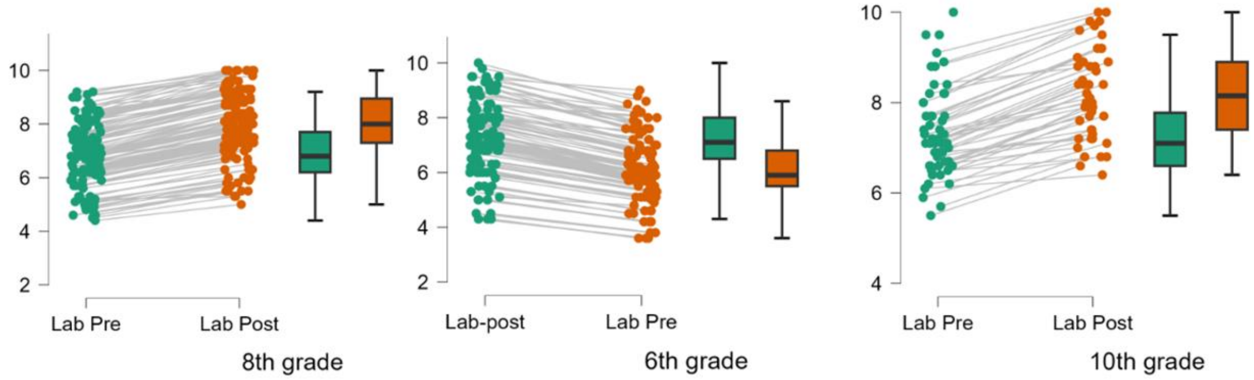
The overall picture of the ICM impact on academic success and laboratory work performance across all participating classes is presented in Table 8. The results include *t-values*, degrees of freedom (*df*), significance levels (*p*), and Cohen's d effect sizes with their standard errors (*SE Cd*). The t-test results indicate statistically significant improvements (p < .001) in both final evaluations and laboratory work for all grades. The Cohen's d values reveal strong to very strong effects, particularly for laboratory performance, where effect sizes range from 2.554 (10th grade) to 4.758 (8th grade), suggesting a profound impact. In comparison, the effect sizes for final evaluations, though still substantial (between 1.198 and 1.677), are also high, consistently lower than those for laboratory work. The standard error (SE) of Cohen's d remains low across all measures, reinforcing the reliability of the effect size estimates. Overall, these results suggest that the intervention had a markedly greater impact on laboratory performance than on final evaluations, with the strongest effects observed in the 8th grade.

Table 8. *The effect of ICM on student performance in final evaluations and laboratory work in the 6th, 8th and 10th grades*

Grade	Measure 1	Measure 2	t	df	p-value	Cohen's d	SE Cd
6th	Evaluation Pre	Evaluation Post	13.179	120	< .001	1.198	0.053
	Lab Pre	Lab-post	48.043	120	< .001	4.368	0.052
8th	Evaluation Pre	Evaluation Post	18.897	126	< .001	1.677	0.034
	Lab Pre	Lab-post	53.617	126	< .001	4.758	0.055
10th	Evaluation Pre	Evaluation Post	11.446	56	< .001	1.516	0.063
	Lab Pre	Lab-post	19.286	56	< .001	2.554	0.076

The effect of ICM on academic success in the 6th, 8th, and 10th grades is illustrated in Fig. 1 and on laboratory works results in Fig. 2.

Figure 2. *The effect of ICM on marks for laboratory works*



Let us now analyse the results regarding the description of the mix of constructivist strategies on the components of scientific competence: DEF (knowledge of definitions), UM (knowledge of units of measurement), FORM (knowledge and application of formulas in problem-solving), PS (ability to solve a problem or translate a problem situation into the terms of a typical physics problem), SL (scientific language or the appropriate and coherent use of learned terms). Each of these five components was measured at the beginning (pre-test) and at the end of the intervention (post-test). For this purpose, students' responses to each item from all evaluations during the academic year were analysed. Each test included items that highlighted each of the five components of scientific competence, scored as 0 – the student does not possess the respective competence – and 1 – the student possesses the respective competence. Thus, Table 9 presents the descriptive statistics for the components of scientific competence in 6th, 8th and 10th grades.

Table 9. *Descriptive statistics for the components of scientific competence*

	6th Grade			**8th Grade**			**10th Grade**		
	Valid	Mean	StD	Valid	Mean	StD	Valid	Mean	StD
DEF Pre	121	0.298	0.459	127	0.323	0.469	57	0.316	0.469
DEF Post	121	0.380	0.487	127	0.425	0.496	57	0.421	0.498
UM Pre	121	0.810	0.394	127	0.780	0.416	57	0.632	0.487
UM Post	121	0.851	0.357	127	0.866	0.342	57	0.807	0.398
FORM Pre	121	0.231	0.423	127	0.244	0.431	57	0.333	0.476
FORM Post	121	0.256	0.438	127	0.339	0.475	57	0.456	0.503
PS Pre	121	0.215	0.412	127	0.189	0.393	57	0.246	0.434
PS Post	121	0.248	0.434	127	0.386	0.489	57	0.456	0.503
SL Pre	121	0.107	0.311	127	0.228	0.421	57	0.298	0.462
SL Post	121	0.347	0.478	127	0.677	0.469	57	0.632	0.487

In order to quickly interpret these data, we will calculate the growth rate for each component of scientific competence in each grade. For this purpose, we will use the formula $Growth\ Rate = (PostTest - PreTest)/PostTest$. The results for the Growth Rate are presented in Table 10.

Table 10. *Growth Rate for the components of scientific competence*

Component	**Growth Rate, 6th Grade**	**Growth Rate, 8th Grade**	**Growth Rate, 10th Grade**
DEF	27.51%	31.63%	33.33%
UM	5.06%	11.03%	27.71%
FORM	10.83%	38.11%	36.90%
PS	15.35%	104.74%	85.37%
SL	224.30%	196.49%	112.08%

Table 11 presents the statistical analysis of the effect of ICM on the components of scientific competence in 6th, 8th, and 10th grades. Large negative t values across all components confirm that ICM had a positive effect on students' scientific competence in all grades (6th, 8th, and 10th). The magnitude of the t values (from 2.274 to 10.129) correlates with the strength of the improvement, with higher

t values indicating greater improvements. For example, the use of scientific language in the 8th and 10th grades or the ability to solve problem situations in the 8th grade showed greater improvements. In general, the t values in Table 10 highlight that ICM had a significant and positive impact on the development of scientific competence, with varying degrees of effectiveness across different components and grades.

The p-values indicate that most results are highly significant ($p < 0.001$), confirming the positive impact of ICM on scientific competence. However, the weakest effects were observed in the 6th grade, specifically in knowledge and the ability to apply simple formulas ($p = 0.083$) and in solving problem situations ($p = 0.045$).

The results for the effect size or Cohen’s d indicate small effects of ICM on knowledge of definitions (DEF) across all grades, and knowledge of measurement units (UM), knowledge and ability to apply simple formulas (FORM), and solving problem situations (PS) in the 6th grade. It is important to note that the relatively small effects for definitions and measurement units are likely due to the fact that students already had a high level of knowledge in these areas before the intervention, leaving limited room for significant improvement. For this reason, ICM shows a moderate effect on UM and DEF in the 8th and 10th grades. Additionally, problem-solving skills (PS) and formulas (FORM) showed moderate improvement, indicating that elder students benefitted more from ICM in structuring and applying knowledge. The most significant improvement was observed in scientific language (SL) in the 8th grade, suggesting that ICM greatly enhanced students’ ability to express and articulate scientific concepts.

The values for the Standard Error of Cohen’s d (SE Cd) help to assess the precision of the effect sizes. Smaller SE Cd values (e.g., for DEF and UM in 6th grade) indicate that Cohen’s d is more precise, suggesting that the positive effects of ICM are reliable in these components. Larger SE Cd values (e.g., for SL in 10th grade) suggest that while the effect of ICM is significant, the effect size estimate is less precise, potentially due to more variability in the data for these components. Overall, the impact of ICM on scientific competence is clear and significant across most components and grade levels.

Table 11. *The effect of ICM on the components of scientific competence*

Component	Grade	t	df	p-value	Cohen's d	SE Cd
DEF	6th	3.288	120	0.001	0.299	0.054
	8th	3.791	126	< .001	0.336	0.057
	10th	2.567	56	0.013	0.340	0.087
UM	6th	2.274	120	0.025	0.207	0.048
	8th	3.457	126	< .001	0.307	0.066
	10th	3.452	56	< .001	0.457	0.118
FORM	6th	1.747	120	0.083	0.159	0.033
	8th	3.626	126	< .001	0.322	0.058
	10th	2.800	56	0.007	0.371	0.092
PS	6th	2.025	120	0.045	0.184	0.039
	8th	5.557	126	< .001	0.493	0.083

	10th	3.864	56	< .001	0.512	0.122
SL	6th	6.150	120	< .001	0.559	0.100
	8th	10.129	126	< .001	0.899	0.117
	10th	5.292	56	< .001	0.701	0.148

Let's now analyse how each of the five components (FORM, PS, SL, DEF, UM) fits within the common construct of scientific competence, referred to as Factor 1 in Table 12. Factor loadings indicate how strongly each component is associated with Factor 1, which represents the overall construct of scientific competence, while uniqueness reflects the proportion of variance in each component that is not explained by that factor.

Across all grades, the FORMULA component (knowledge of formulas and the ability to apply them to simple problems) and PS (the ability to solve problem situations or translate a verbally stated real-life problem into a typical one) show high and very high loadings, suggesting that they contribute significantly to the underlying construct. In addition, the DEFINITION component (knowledge of definitions of recently studied scientific quantities) and SL (the proper and coherent use of scientific terms) exhibit mostly moderate loadings, indicating that these components also contribute meaningfully to the common construct. The low uniqueness values of these four components suggest that they are well explained by the construct of scientific competence. In contrast, UM (knowledge of measurement units) exhibits lower loadings and higher uniqueness, especially in the 6th and 8th grades, indicating that this component is less integrated into the overall construct of scientific competence.

Table 12. *Factor loadings for the components of scientific competence*

	6th Grade		**8th Grade**		**10th Grade**	
	Loading Factor 1	Uniqueness	Loading Factor 1	Uniqueness	Loading Factor 1	Uniqueness
Formula	0.927	0.140	0.879	0.227	0.945	0.107
PS	0.907	0.178	0.945	0.107	0.835	0.302
SL	0.808	0.347	0.644	0.586	0.791	0.375
Definition	0.762	0.420	0.929	0.136	0.810	0.344
UM		0.896	0.415	0.828	0.546	0.702

In order to better understand the relationship between the components of scientific competence, let's examine the rotated and unrotated solutions presented in the Table 13. These solutions provide a deeper insight into how the five components (FORM, PS, SL, DEF, UM) load onto the common construct of scientific competence and help us assess the strength and clarity of their relationships within the overall factor structure.

Thus, the high Eigenvalues (3.304 − 3.487) indicate that the main factor (scientific competence) captures information from approximately three components out of the five analyzed. These would be: FORMULA, PS, SL, and to some extent, DEFINITION. Additionally, the slight increase in the Eigenvalue from the 6th grade to the 10th grade shows that the structure of scientific competence in students is established early on and does not undergo essential changes but rather refines over time without being restructured.

The Sum of Squared Loadings remains almost constant (~3) and the same across both unrotated and rotated solutions. This means that the scientific competence factor explains approximately the same proportion of variance in the data across all grades.

The values of the Proportion of Variance and the Cumulative Proportion of Variance remain the same for both Rotated and Unrotated Solutions, ranging from 0.604 in the 6th grade to 0.634 in the 10th grade. This indicates that approximately 60% of scientific competence is explained by these components. This confirms that three of the five components fit into the general construct of scientific competence.

Table 13. *The characteristics of the scientific competence factor for rotated and unrotated solutions*

Grades	Solution	Eigenvalue	Sum Sq. Loadings	Proportion var.	Cumulative
6th	Unrotated	3.304	3.019	0.604	0.604
	Rotated		3.019	0.604	0.604
8th	Unrotated	3.383	3.117	0.623	0.623
	Rotated		3.117	0.623	0.623
10th	Unrotated	3.487	3.170	0.634	0.634
	Rotated		3.170	0.634	0.634

Results and Discussion

Regarding the answer to RQ1: “How does the integration of constructivist teaching strategies in physics influences the academic success of students at different school levels?”, the research findings allow us to state the following:

At the lower secondary level, specifically in 6th grade, when students encounter physics for the first time in school, the implementation of the ICM model throughout the academic year led to the following outcomes:

- Students’ marks on summative assessments at the end of the year increased by approximately 10% compared to the beginning of the year (see Table 3), with a moderate Progress Index (PI = 0.572).
- Final laboratory work marks improved by about 17% from the start of the year (see Table 3), with a strong Progress Index (PI = 0.887).
- The correlation between laboratory results and summative assessments is approximately 60% (see Table 6), meaning that a 0.6 increase in the assessment grade corresponds to a 1.0 increase in the laboratory grade. This further confirms the influence of “doing” on “learning” and highlights the necessity of a constructivist approach to achieve higher learning outcomes.

At the upper secondary level, specifically in 8th grade, the following results were obtained:

- The marks on summative assessments increased by approximately 8.3% (see Table 4), with an average score of 7.75 and a moderate Progress Index (PI = 0.611). The relatively small percentage increase in marks is due to the saturation effect: before the intervention, the students had already answered these items correctly at a rate of 80%. The impact of the ICM model on academic performance is also clearly visible in the analysis of skewness values. At the pre-test, skewness was nearly zero (0.005), indicating a symmetric distribution of student marks, while at the post-test, it became slightly negative (-0.144), meaning that a higher number of students obtained high grades, with fewer students receiving low grades (see Table 4).
- Laboratory work marks increased by 15.7%, with an average of 7.95 and a strong Progress Index (PI) = 0.921 (see Table 4). The effect of the ICM model is also evident in this case: at the pre-test, skewness was slightly negative (-0.027), and after the intervention, it became more pronounced (-0.325), indicating an increase in the proportion of students with high grades.
- The correlation between laboratory and assessment results is higher than in 6th grade, reaching 77.5% (see Table 6). In other words, an increase of one unit in the laboratory average should lead to an increase of approximately 0.77 in the assessment average.

At the high school level, specifically in 10th grade, the following results were obtained:

- Assessment scores increased by 8.9%, with an average of approximately 7.80 (see Table 5). The Progress Index in this case is moderate, PI = 0.563.
- Laboratory scores increased by 14.1%, with an average of approximately 8.70, showing a strong PI = 0.816. The high and positive skewness values in 10th grade indicate that most students have high scores, with only a few students scoring lower.
- The correlation between laboratory work and assessments reached approximately 51%.

Additionally, it is interesting to examine the impact of the ICM model on academic performance among high, medium, and low achievers. At all levels, the average scores increased as follows:

- In 6th grade: high achievers' scores increased by 1.111 units, medium achievers by 0.697 units, and low achievers by 0.35 units.
- In 8th grade: high achievers' scores increased by 0.839 units, medium achievers by 0.749 units, while the increase for low achievers was insignificant.
- In 10th grade: high achievers' scores increased by 0.882 units, medium achievers by 0.615 units, and low achievers by 0.4 points.

Thus, the increase in scores for high achievers is greater than for low achievers — three times higher in 6th grade and twice in 10th grade.

Overall, the effect size of the ICM model (Cohen's d) on academic performance ranges from 1.198 to 1.516, indicating a strong effect, while for laboratory work, it ranges from 4.368 to 2.554, corresponding to a very strong effect (see Table 8). This larger effect size in laboratory work compared to assessments was expected since ICM is primarily a constructivist method. To achieve a similar increase in assessments, it would be necessary to enhance the use of teaching strategies related to metacognition and feedback.

Regarding the answer to RQ2, "What is the impact of the method on the components of students' scientific competence?" we can state that the effect of ICM on the scientific components of students in different grades was as follows:

- For 6th-grade students, the highest growth rate was observed in the use of scientific language (SL), with an increase of approximately 224%, followed by the memorization of definitions (DEF) at around 27%.
- For 8th-grade students, the highest growth rate was also in SL—about 196%—and in solving real-life problem situations (PS), with an increase of approximately 105%.
- For 10th-grade students, a similar trend was observed: SL increased by 112%, while PS grew by 85% (see Table 10).

Thus, the results for the effect size, or Cohen's d (see Table 11), indicate the highest effect size for SL, ranging from 0.559 to 0.899 across different grades, suggesting that ICM significantly enhanced students' ability to express and articulate scientific concepts. Next, PS and the ability to apply formulas in simple problems (FORM) show effect sizes ranging from 0.184 to 0.512. In third place, FORM ranges from 0.159 to 0.371, corresponding to a moderate improvement. The smallest effect size of ICM is observed for knowledge of definitions (DEF), ranging from 0.299 to 0.340, and knowledge of measurement units (UM), ranging from 0.207 to 0.457. This can be explained by the saturation effect, as students had already answered these test items at approximately 80% accuracy in the pre-test.

We have to mention that factor analysis indicates that the scientific competence is formed by approximately three components out of the five analysed: FORMULA, PS, SL, and to some extent, DEFINITION. Thus, about 60% of scientific competence is determined by these three-four components. Also, we established that the structure of scientific competence in students is established early on and does not undergo essential changes but rather refines over time without being restructured.

Conclusions

This study was based on the idea of applying RBIS when designing a teaching approach or strategy. Additionally, it was founded on the premise that overlapping elements of constructivist teaching strategies with a confirmed effect size adds value. In other words, we can refer to the Concept of Didactic Synergy, where the effect size of the mix of teaching strategies is greater than the highest effect of its individual components.

Based on these considerations, the Integrated Constructivist Model (ICM) was developed, incorporating elements from the 5E Model, Flipped Classroom, Peer Instruction with Conceptual Questions, and the Early Physics Approach. Thus, both research hypotheses were confirmed.

The effect size values obtained for assessments indicate a moderate to strong effect of ICM (1.198; 1.677) and a strong to very strong effect on laboratory work results (2.554; 4.758).

Additionally, the analysis of scientific competence components revealed significant progress in the use of scientific language (SL) and problem-solving ability (PS). These competencies showed favourable effect sizes, with values reaching 0.899 for SL and 0.512 for PS, highlighting that ICM enhanced not only the learning of theoretical information but also students' ability to express themselves coherently in scientific terms.

Furthermore, after one year of ICM implementation, the success rate of high achievers increased significantly more than that of low achievers—three times in the 6th grade and twice in the 10th grade.

Therefore, the systematic integration of these constructivist strategies into daily teaching is recommended to maximize students' academic outcomes.

In conclusion, the positive impact of ICM, built on the concept of Didactic Synergy, observed in academic performance and the development of scientific competencies, suggests that a well-designed constructivist pedagogy can transform the learning experience in physics, enhancing students' motivation and engagement in science (Hattie, 2009; Zhou, 2004; Bonacci, 2020).

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