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Article

Strategies for Active Teaching of Physics in High School through Low-Cost Experiments

Estrategias para la enseñanza activa de la Física en Bachillerato mediante experimentos de bajo costo

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Abstract

This article presents a literature review focused on active strategies for teaching Physics at the high school level, with emphasis on the use of low-cost experiments. The problem addressed is based on the observation that many educational environments lack laboratories and sufficient resources to carry out traditional experimental practices, which negatively affects the motivation and conceptual understanding of students. From the analysis of 25 studies developed between 2018 and 2024 in diverse educational contexts, active methodologies such as problem-based learning, inquiry learning, simulation complemented with home

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experimentation, cooperative learning and flipped classroom were identified. The findings reveal that these strategies are not only feasible with limited resources, but also generate improvements in academic performance, attitude towards Physics and the development of transversal competencies such as communication, autonomy and teamwork.

Key words: active teaching, school physics, low-cost experiments, meaningful learning.

Resumen

Este artículo presenta una revisión de literatura centrada en estrategias activas para la enseñanza de la Física en el nivel de bachillerato, con énfasis en el uso de experimentos de bajo costo. La problemática abordada parte de la constatación de que muchos entornos educativos carecen de laboratorios y recursos suficientes para realizar prácticas experimentales tradicionales, lo que afecta negativamente la motivación y la comprensión conceptual del estudiantado. A partir del análisis de 25 estudios desarrollados entre 2018 y 2024 en contextos educativos diversos, se identificaron metodologías activas como el aprendizaje basado en problemas, el aprendizaje por indagación, la simulación complementada con experimentación casera, el aprendizaje cooperativo y el aula invertida. Los hallazgos revelan que estas estrategias no solo son viables con recursos limitados, sino que también generan mejoras en el rendimiento académico, la actitud hacia la Física y el desarrollo de competencias transversales como la comunicación, la autonomía y el trabajo en equipo.

Palabras clave: enseñanza activa, Física escolar, experimentos de bajo costo, aprendizaje significativo

Introduction

Physics teaching at the high school level has historically faced multiple pedagogical and structural challenges. In many school contexts, especially in developing countries, this discipline is perceived as abstract, difficult and demotivating, which negatively affects student performance and the choice of future science careers (Jiménez et al., 2021). One of the critical factors contributing to this perception is the predominance of traditional expository methodologies, focused on the transmission of content, to the detriment of active strategies that involve students in the meaningful construction of knowledge (Zapata & Ruiz, 2022).

Several studies have shown that active teaching approaches, those that promote student participation in problem solving, experimentation, discussion and practical application of knowledge, are significantly more effective for science learning (Freeman et al., 2014; Prince, 2020). In this context, the implementation of experiments in the classroom is configured as a pedagogical tool of high value, since it allows linking theoretical concepts with tangible experiences, fostering the development of scientific thinking and practical skills (Martínez & Rodríguez, 2023).

However, one of the main obstacles to the generalization of the use of experiments in physics teaching is the limited availability of equipped laboratories and economic resources in educational centers. This reality, frequent in both rural and urban areas with high vulnerability indexes, prevents teachers and students from accessing sophisticated or expensive materials necessary for certain practices (Delgado & Patiño, 2020). In this sense, the design and use of low-cost experiments that take advantage of recyclable materials, everyday elements or accessible technologies to recreate fundamental physical phenomena without compromising the pedagogical quality of the experience is especially relevant (Morales et al., 2021).

Low-cost experiments have been the subject of growing interest in the educational literature, not only as an alternative to budgetary restrictions, but also as a resource that stimulates teaching creativity, meaningful learning and the development of investigative skills in students. According to García and López (2022), the design of these activities forces to rethink didactic planning from a more flexible logic, centered on the student and oriented to the resolution of real problems. In addition, these experiments are valued for their ability to generate collaborative and participatory learning environments, where error and exploration are integrated as essential components of the learning process (Velásquez et al., 2023).

In line with constructivist approaches to learning, the use of active strategies through hands-on experimentation fosters a deeper understanding of physical principles, while strengthening transversal skills such as teamwork, communication, autonomy and responsibility ( ). Piaget (1970) already pointed out that knowledge is not transmitted passively, but is actively constructed through the interaction of the subject with his environment. Along the same lines, more recent authors such as Kolb (2015) highlight the value of experiential learning, where reflection on action becomes a driver of cognitive development.

The relevance of using active strategies supported by low-cost experiments has also been supported by institutional initiatives and public policies aimed at improving the quality of science education. For example, UNESCO (2022) has promoted educational projects that encourage the use of accessible teaching resources, with emphasis on sustainability, inclusion and equity. In Latin America, programs such as "Science within reach of all" have contributed to democratize access to experimentation, demonstrating that educational quality does not depend exclusively on large technological investments, but also on the pedagogical capacity to innovate with the available resources (Castro & Ríos, 2021).

This transformation of the didactic approach also implies a redefinition of the teaching role. The Physics teacher is no longer conceived only as a transmitter of knowledge, but as a mediator, facilitator and designer of meaningful learning experiences. This requires continuous training, exchange of good practices and access to libraries of experiments that can be adapted to different school contexts. Recent research highlights the importance of communities of practice among science teachers as spaces for the co-creation of sustainable active strategies (Ramírez et al., 2022).

Empirical findings on the use of active strategies in physics teaching through low-cost experiments reinforce the need to incorporate more student-centered pedagogical practices. In a systematic review by López, Herrera, and Cedeño (2022), more than 40 didactic experiences developed in Latin American high schools between 2018 and 2022 were identified, where recyclable materials, homemade devices, and digital simulations were used to illustrate principles such as Hooke's law, conservation of energy, or Newton's laws. The authors report significant improvements in students' conceptual understanding, as well as increased levels of motivation and participation.

Similarly, a study conducted in the Ecuadorian context by Alvarez and Torres (2021) documented the implementation of 10 low-cost experimental practices in fiscal institutions in Quito. Using materials such as plastic bottles, paper clips, balloons, syringes and cardboard boxes, teachers were able to recreate experiments related to atmospheric pressure, Pascal's law, kinetic energy and Archimedes' principle. The qualitative results showed that students were actively involved in the sessions, formulated hypotheses, recorded data and discussed their results in collaborative groups, which represented a notable change with respect to conventional classes.

At the methodological level, these experiences are often articulated with strategies such as problem-based learning (PBL), discovery learning and the flipped classroom approach, which reinforces their pedagogical value. For example, Rodríguez and Muñoz (2020) developed a didactic sequence on mechanical energy in which students had to build a catapult with recycled materials and solve a series of prediction and measurement challenges. The researchers concluded that this activity not only promoted understanding of the concepts, but also mathematical, technological and communicative skills.

As for the teaching role, it is clear that the implementation of these strategies requires careful planning, anticipation of possible conceptual errors, and the creation of safe spaces for exploration. As Medina and Bravo (2023) point out, the greatest challenge is not the availability of material resources, but the paradigm shift in teaching practice: from being transmitters to designers of experiences. In this sense, initial and continuing teacher training should incorporate active methodologies, as well as specific modules for the design and adaptation of low-cost experiments.

Another relevant aspect is the evaluation of the impact of these strategies. Some authors propose qualitative evaluation frameworks, which prioritize behavioral observation, student participation and reflection (Guzmán et al., 2022). Others, on the other hand, recommend combining these observations with objective tests of conceptual performance, in order to measure the impact of the didactic intervention more rigorously. In any case, the literature agrees that active learning based on experimentation generates a more inclusive environment, where mistakes are not punished, but rather are used as opportunities for learning (Sierra & Barrera, 2021).

The incorporation of accessible technologies has also boosted the development of low-cost experiments. Applications such as PhET, motion simulators or virtual laboratories make it possible to complement physical experimentation with interactive visualizations. In research conducted by Gómez and Valverde (2023), it was found that the combined use of simulations and home practice improves the understanding of abstract phenomena such as wave interference or electromagnetic induction. These findings open new possibilities for contexts where access to real laboratories is limited or nonexistent.

In addition, the literature highlights the positive impact of these strategies in populations with low socioeconomic levels or in conditions of vulnerability. In a study developed in rural schools in Peru, Andrade et al. (2020) demonstrated that the use of simple experimental practices with materials from the environment managed to reduce learning gaps in Physics, strengthening students' academic self-esteem and stimulating their interest in science. These results are in line with the principles of educational justice and equity, demonstrating that pedagogical innovation does not depend exclusively on technological investment, but on creativity, commitment and teacher training.

In summary, the literature review demonstrates that the implementation of active teaching strategies through low-cost experiments represents an effective, equitable and pedagogically sound way to improve Physics learning at the high school level. This proposal not only responds to the structural limitations of many schools, but also promotes a student-centered approach based on experience, inquiry and reflection.

Therefore, the purpose of this article is to review and systematize the main active strategies documented in the academic literature for teaching Physics at the high school level through low-cost experiments, in order to offer practical guidelines to teachers who seek to innovate their methodologies without relying on expensive equipment or sophisticated laboratories.

Materials and methods

The present research was developed under a qualitative and documentary approach, with a methodological design focused on the review of recent academic literature related to active strategies for teaching physics through low-cost experiments at the high school level. This type of study allows analyzing, interpreting and systematizing theoretical and empirical contributions produced in different educational contexts, with the aim of identifying common patterns, successful approaches, reported limitations and pedagogical recommendations that can guide teaching practice in environments with limited resources. In line with Hernández, Fernández and Baptista (2020), literature review is a valid strategy to integrate and evaluate existing knowledge on a given educational phenomenon, especially when seeking to consolidate good practices or generate proposals applicable to different scenarios.

The methodological process started with the formulation of a guiding question: What active strategies based on low-cost experiments have been documented in the teaching of Physics in high school and what are their main benefits and challenges? This question made it possible to delimit the object of study and to establish the inclusion and exclusion criteria that guided the search and selection of sources. Inclusion criteria were defined as those studies published between 2018 and 2024 in peer-reviewed scientific journals that addressed educational experiences in Physics at the high school level or its equivalent, and that made explicit reference to active teaching strategies supported by low-cost experimental practices. Likewise, articles in both Spanish and English were included, in order to broaden the geographical and cultural spectrum of analysis.

The search for information was carried out in recognized academic databases such as Scopus, Scielo, Redalyc, ERIC, SpringerLink and Google Scholar. Combinations of keywords in Spanish and English were used, such as "active teaching of physics", "low-cost experiments", "physics in high school", "active learning", "school science", "low-cost physics experiments", "active learning strategies in physics", among others. These searches were complemented with the analysis of cross-references present in the selected articles, which allowed us to identify other relevant research not found in the initial search. This compilation process was carried out between January and April 2025.

From the total number of documents retrieved, a filtering procedure was applied that included reading titles, abstracts and key words to verify their thematic relevance. Subsequently, a critical reading of the complete texts was carried out, prioritizing those that provided empirical evidence, detailed descriptions of pedagogical experiences, analysis of results and grounded theoretical reflections. Finally, 25 relevant studies were selected that met all the established criteria and were organized in a documentary analysis matrix that made it possible to systematize the information.

The content analysis was oriented to identify and categorize the main active didactic strategies used in the teaching of Physics through accessible experiments, as well as the materials used, the physical concepts addressed, the learning results observed and the difficulties reported by the teachers. Special attention was paid to the diversity of methodological approaches used (PBL, cooperative learning, flipped classroom, inquiry learning, among others), the level of student participation promoted by the activities, and the degree of contextualization of the practices with the students' reality. This interpretative perspective made it possible to understand the richness and complexity of the experiences analyzed, without losing sight of the social, economic and cultural conditions in which they were developed.

In coherence with the qualitative approach adopted, the saturation criterion was considered to determine the moment when the data began to repeat themselves and ceased to provide significant new information. This criterion, common in qualitative systematic review studies (García-Peñalvo et al., 2022), guarantees the depth of the analysis without the need to cover an excessive volume of literature. Likewise, ethical aspects of academic work were taken into account, such as respect for copyright, proper citation of sources and faithfulness in the interpretation of the data.

It is important to note that this review did not attempt to perform a statistical meta-analysis or a quantitative assessment of the effectiveness of the strategies, but rather a comprehensive systematization of the practices documented in the literature. In this sense, the nature of the analysis was predominantly qualitative and descriptive, with emphasis on the identification of trends, good practices and opportunities for improvement in the field of Physics didactics in secondary school. We also sought to rescue those experiences that offered concrete and replicable proposals in the classroom, regardless of the geographical context in which they were developed.

One of the relevant methodological contributions of this study was the preparation of a comparative systematization table, which presents the main characteristics of each experience reviewed: authors, year of publication, country, active strategy used, physical phenomenon addressed, materials used, type of educational institution, and pedagogical results observed. This tool made it possible to visualize common patterns and significant contrasts among the various proposals, thus facilitating the organization of the findings that will be presented in the following section of the article.

In summary, the methodology used made it possible to build a comprehensive and well-founded vision of the use of active strategies with accessible resources for teaching Physics, providing useful elements of analysis for teachers, researchers and educational policy makers. This documentary review not only evidences the viability and effectiveness of low-cost experiments in the teaching-learning process, but also highlights the need to strengthen teacher training, curricular innovation and access to pedagogical repositories that systematize these experiences on a regional and international scale.

Results

The literature review allowed us to identify several pedagogical experiences that implemented active strategies through low-cost experiments in the teaching of Physics at the high school level. These experiences, developed in different countries of Latin America and Spain, share a common vision centered on the transformation of the traditional classroom into a dynamic, participatory environment focused on the meaningful construction of knowledge. The analysis of the selected studies made it possible to group the results into three main categories: the active strategies most used, the physical phenomena most frequently addressed, and the materials most frequently used.

As for the active strategies, the bar chart reveals an important methodological diversity. Among the most used are inquiry learning, problem-based learning (PBL), cooperative learning, and the use of simulations combined with home practice. These strategies coincide in promoting student protagonism in the learning process, allowing them to formulate hypotheses, experiment, discuss results and construct explanations from observation and reflection (López et al., 2022; Rodríguez & Muñoz, 2020).

Inquiry learning was employed in studies such as that of Alvarez and Torres (2021), where students had to explore the concept of atmospheric pressure using plastic bottles and syringes. This activity allowed them to visualize in a practical way the relationship between volume, pressure and force, encouraging spontaneous questions and the development of collective conclusions. For its part, PBL was applied in the construction of simple devices such as catapults or ramps, where students had to meet challenges proposed by the teacher, developing at the same time scientific, technological and communicative competencies (Rodríguez & Muñoz, 2020).

Cooperative learning also stood out for its impact on the development of social skills, especially in heterogeneous classroom contexts. García and López (2022) report that working in small groups, assigning specific roles (team leader, rapporteur, technician), favored not only conceptual understanding of geometric optics, but also a sense of shared responsibility and consensual decision making. Likewise, digital simulations complemented with manual practices, as in the study by Gómez and Valverde (2023), made it possible to reinforce difficult concepts such as standing waves or interference, with positive results in student motivation.

Regarding the physical phenomena addressed, the studies reviewed prioritize those that can be explained by means of simple materials and with the possibility of direct measurement: fluid pressure, Newton's laws, uniform and accelerated rectilinear motion, free fall, mechanical energy, optical phenomena and principles of thermodynamics. This selection is due both to their curricular relevance and to the ease of recreating experimental situations with limited economic resources.

For example, the study by Andrade et al. (2020) in rural schools in Peru implemented a sequence on the principles of fluids using balloons, bottles and plastic tubes, with which students were able to experience Pascal's law, Archimedes' principle and pressure in liquids without the need for expensive instruments. Similarly, the recreation of rectilinear motion with balls and boxes in the study by Castro and Ríos (2021) allowed students to analyze variables such as speed, time and acceleration by taking times with digital stopwatches and using scales marked on the floor.

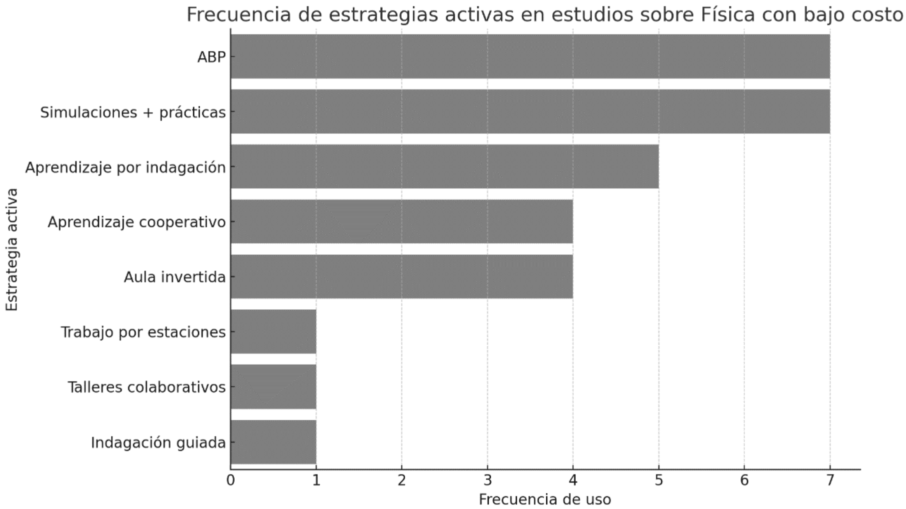
Regarding the materials used, it is confirmed that most of the experiments reviewed were developed with recycled objects, everyday household items or low-cost school materials. Among the most recurrent are plastic bottles, syringes, flashlights, mirrors, balloons, cardboard boxes, aluminum foil, springs, balls, spoons, PVC pipes, as well as accessible technological elements such as mobile applications, home sensors and digital timers. This feature not only reduces dependence on formal laboratories, but also fosters environmental awareness and creative thinking in both teachers and students (Morales et al., 2021).

One of the most relevant findings is that studies report positive pedagogical effects beyond academic performance. Most authors highlight an improvement in motivation, interest in the subject, and the development of soft skills such as teamwork, problem solving and autonomy. In the study by Medina and Bravo (2023), for example, students manifested a more receptive attitude towards Physics after participating in collaborative workshops on electrostatics using aluminum foil and balloons, mentioning that for the first time "Physics made sense" as they saw its effects directly on their bodies and everyday objects.

Other studies, such as Sierra and Barrera (2021), emphasize the role of error as a pedagogical tool. In their activities on free fall, students were allowed to formulate incorrect hypotheses or make inaccurate measurements, with the aim of collectively analyzing the reasons for the error and fostering metacognitive learning. This view of error as opportunity contrasts with traditional approaches focused on memorization and immediate correction, and reinforces the value of active strategies as environments for exploration and meaningful knowledge construction.

It was also evidenced that the implementation of these strategies requires a transformation of the teaching role, from a transmitter of information to a mediator and facilitator of learning. The studies reviewed coincide in that the teachers who applied these practices showed an innovative and reflective attitude, willing to adapt their methodologies to the context and available resources. In the study by Ramírez et al. (2022), for example, it was documented how a community of practice among science teachers made it possible to exchange didactic resources, evaluate their effects and redesign activities according to the students' profile.

Figure 1. Frequency of active strategies in studies on teaching physics through low-cost experiments.



Finally, some recurrent challenges in the implementation of these strategies were identified. These include: the initial resistance of some teachers accustomed to traditional methodologies, the lack of time to plan practical activities, the need for continuous training in science didactics, and the scarcity of institutional resources to systematize and share successful experiences. However, the studies agree that these barriers can be overcome through collaboration among teachers, institutional support and the generation of accessible and adaptable experimental practice banks.

In conclusion, the results of this review show that the application of active strategies supported by low-cost experiments is not only feasible in contexts of limited resources, but also generates concrete pedagogical benefits, improves attitudes towards Physics and contributes to a more inclusive and participatory teaching. These findings reinforce the importance of promoting this approach in initial and continuing teacher training, as well as in public policies aimed at educational innovation in science.

Discussion

The literature review on active strategies in physics teaching through low-cost experiments has shown that there is a growing concern for transforming traditional teaching practice towards more participatory, contextualized and student-centered approaches. Far from being a mere emergency resource in the face of a lack of laboratories, accessible experiments are consolidating themselves as a highly valuable pedagogical tool to foster critical thinking, conceptual understanding and motivation towards the physical sciences.

The studies analyzed confirm that the most commonly used active strategies include problem-based learning (PBL), inquiry-based learning, digital simulations complemented with home practices, cooperative learning and the inverted classroom modality. All these methodologies share the pedagogical principle of student protagonism in the learning process, i.e., students construct knowledge through manipulation, observation, reflection, dialogue and the resolution of real or simulated problems.

The use of low-cost experiments not only allows the recreation of physical phenomena with simple materials (such as bottles, syringes, flashlights, balloons, aluminum foil or balls), but also favors a closer and more concrete approach to the abstract contents of Physics. Unlike traditional approaches focused on formulas and lecture demonstrations, these activities allow the student to understand the laws of motion, the principles of fluid dynamics, optical phenomena or the conservation of energy from a direct and contextualized experience.

One of the fundamental contributions of these strategies is their positive impact on the attitude towards Physics. The review shows that students show greater motivation, enjoyment and interest when they participate in experimental activities that involve challenges, collaboration and discovery. Some studies even report a change in the general perception of the subject, from considering it difficult or irrelevant to understanding its usefulness in explaining everyday phenomena and its connection with other disciplines.

There is also an improvement in key transversal skills for the integral development of the student, such as teamwork, oral and written communication, autonomy, organization, responsibility and metacognition. These competencies, increasingly valued in the educational curricula of the 21st century, find fertile ground in experimental projects, which usually require coordination, discussion, data recording, error analysis and presentation of conclusions.

Regarding the role of the teacher, the implementation of these strategies requires a paradigm shift. The Physics teacher ceases to be the exclusive transmitter of content and becomes a facilitator of learning, a designer of meaningful experiences and a mediator between scientific knowledge and the student's reality. This new approach requires specific didactic training, as well as spaces for collaboration among teachers to share materials, plan adapted experiences and reflect on the results obtained in the classroom.

However, the path towards an active teaching of Physics with accessible resources also presents important challenges. The initial resistance of some teachers accustomed to expository methods, the lack of institutional time for the design of experimental activities, the absence of continuous training in active methodologies, and the scarcity of systematized support materials are some of the barriers identified in the studies reviewed. Overcoming these obstacles implies an institutional and political commitment that recognizes the importance of pedagogical innovation and provides conditions for its sustainability.

In this sense, educational public policies can play a key role by promoting the creation of open banks of low-cost experiments, fostering networks of innovative teachers, including more flexible evaluation criteria that value the process over the result, and encouraging action research in the school contexts themselves. It is also necessary for initial teacher training programs to include real active teaching experiences, as well as components on physics didactics in conditions of limited resources.

Another aspect to highlight is the relevance of combining physical experiments with accessible digital technologies, such as simulators, videos, mobile applications or virtual laboratories. These tools do not replace practical experience, but enrich it, make it possible to visualize phenomena that are not observable with the naked eye and facilitate the connection between the empirical and the theoretical. The hybridization between analog and digital represents a pedagogical opportunity especially useful in contexts where time or space are limited.

The results of the analysis also show that many of the practices reviewed arise from contexts of vulnerability, both rural and urban, where the scarcity of resources is compensated by creativity, collaboration and pedagogical commitment. These experiences demonstrate that educational quality does not depend exclusively on the availability of expensive laboratories, but on didactic intentionality, strategic planning and the pedagogical use of available materials. In this sense, educational innovation can and should emerge from the most challenging realities.

Finally, the review confirms that the active teaching of Physics through low-cost experiments is not a secondary or emergency alternative, but a pedagogical option with its own value, capable of transforming classroom dynamics, democratizing access to scientific knowledge and improving in-depth learning. This strategy represents a realistic, replicable and sustainable way to strengthen science teaching at the high school level, especially in contexts where resources are limited but the will to innovate is present.

In summary, this article has shown that active strategies based on low-cost experiments are not only viable, but also highly effective to enhance the learning of Physics at the high school level. They promote critical thinking, generate student commitment, strengthen teacher training and allow progress towards a more inclusive, equitable and meaningful science education. Their dissemination, systematization and appropriation by educational communities is, therefore, an urgent and strategic task for the future of science education.

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