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Experimental physics teaching in primary education: Progress, barriers, and lessons from a 23-year Greek study

Konstantinos T. Kotsis [1]*

[1] Department of Primary Education, University of Ioannina, Ioannina, GREECE
***Corresponding Author:** kkotsis@uoi.gr

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ABSTRACT

Experimental teaching is a vital component of science education, enabling students to actively interact with physical phenomena and cultivate inquiry skills necessary for scientific literacy. This longitudinal study investigates the progression of experimental teaching methodologies in Greek primary education over a span of 23 years (2001-2024), with particular emphasis on physics instruction. This study analyzes changes in teachers' practices, perceptions, and perceived obstacles related to teacher-led experimental demonstrations and student-centered experimentation, based on four consecutive survey waves conducted in the Ioannina region. The findings indicate notable advancements in the frequency and educational incorporation of experimental activities, alongside enduring systemic limitations, such as inadequate laboratory facilities, time constraints, and apprehensions regarding student safety. The research emphasizes the intricate interplay among curricular reform, professional development, and institutional factors that influence the progression of science education. The findings provide significant insights for both domestic and global initiatives aimed at advancing inquiry-based science education in primary schools.

Keywords: experimental pedagogy, inquiry-based learning, elementary education, physics instruction, scientific literacy

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INTRODUCTION

Physics instruction, as a fundamental component of science education, is vital for cultivating scientific literacy, analytical skills, and inquisitive mindsets in future citizens from an early age. In contemporary societies, where scientific knowledge increasingly influences public discourse, technological progress, and policy decisions, fostering critical thinking skills regarding scientific issues in young learners has emerged as a primary objective of global education systems. Initial encounters with scientific inquiry significantly shape students' perceptions of science and their readiness to interact with scientific material in subsequent educational phases and thereafter (Kotsis, 2024). Nonetheless, instructing science–especially physics–at the elementary level presents considerable pedagogical difficulties. Numerous fundamental concepts in physics are abstract and not directly perceivable. Concepts such as forces and motion, energy transformations, electric and magnetic interactions, and wave behavior are frequently imperceptible or counterintuitive for young learners. In the absence of adequate mediation, instruction may remain superficial or merely verbal, neglecting to confront students' pre-existing misconceptions regarding the physical world (McDermott, 2004).

In this context, experimental teaching arises as a crucial pedagogical strategy. The incorporation of practical experiments into science education enables students to actively interact with physical phenomena, fostering learning processes that transcend mere rote memorization or passive information absorption. By engaging in the design, observation, and analysis of experiments, students develop essential scientific competencies, such as meticulous observation, precise measurement, hypothesis formulation, evidence assessment, and data-driven reasoning (Hofer et al., 2018). Moreover, experimental endeavors can ignite curiosity and intrinsic motivation by offering learners the chance to investigate personally significant inquiries and relish the exhilaration of discovery. Extensive research indicates that meticulously crafted experimental activities markedly improve students' comprehension of fundamental scientific concepts and promote inquiry-based learning, as well as the cultivation of scientific dispositions such as skepticism, receptiveness to evidence, and collaborative problem-solving (Duit & Tesch, 2010; Josey et al., 2018).

The advantages of experimental teaching are especially apparent in primary education, where students' innate curiosity and creativity are most pronounced. When experiments are tailored to be age-appropriate and grounded in everyday contexts, they serve as effective instruments for connecting formal scientific concepts with students' lived experiences (Miškář, 2019). Moreover, employing basic, inexpensive materials in experimental endeavors guarantees that these methods remain attainable even in resource-constrained educational environments–a vital factor in numerous public school systems (Tiberghien et al., 1995). Fostering a culture of inquiry and experimentation from an early age in primary physics education can substantially advance the overarching objective of scientific literacy and equip students to thoughtfully confront the scientific and technological challenges of the 21st century.

THE ROLE OF HANDS-ON EXPERIMENTS IN PRIMARY PHYSICS EDUCATION

Practical experiments are essential for cultivating significant learning experiences in primary physics education. They offer students opportunities to directly interact with physical phenomena and to cultivate both conceptual comprehension and inquiry-related skills. Unlike conventional didactic methods that primarily rely on verbal explanations or textbook readings, experiential experiments enable learners to actively engage in the construction of their comprehension of scientific concepts (Voitkiv & Lishchynskyy, 2023). Students participate in processes that reflect genuine scientific practice by designing and executing experiments: they formulate investigable questions, generate predictions based on existing knowledge, plan and perform observations, manipulate variables, gather and analyze data, and adjust their reasoning in light of empirical evidence (Wood & Blevins, 2019).

Such experiences are especially beneficial in the instruction of physics, a field marked by significant abstraction and mathematical rigor. Young learners frequently struggle to comprehend concepts such as force, energy, motion, and waves when they are conveyed exclusively through symbolic representations or verbal descriptions. Practical experiments offer specific contexts for the exploration and realization of these abstract principles (Stylos & Kotsis, 2021). By engaging directly through sight, touch, and manipulation, students can connect everyday experiences with scientific models, thereby alleviating enduring misconceptions and promoting a more profound comprehension. For instance, by experimenting with simple pendulums, ramps, or circuits, students not only observe phenomena but also challenge and amend intuitive yet erroneous beliefs regarding causality and physical interactions (Josey et al., 2018).

Furthermore, practical experimentation in primary physics education fosters the acquisition of diverse transversal competencies that are increasingly acknowledged as essential to scientific literacy. This encompasses abilities in observation, measurement, data analysis, evidence-based reasoning, and critical thinking, alongside collaborative competencies such as teamwork, communication, and the aptitude to negotiate and refine concepts through social interaction. Significantly, involving students in experimental inquiry cultivates affective outcomes, including curiosity, persistence, and a favorable attitude toward science education–outcomes crucial for maintaining engagement with science throughout the educational journey (Dvořáková & Prošková, 2019).

In the primary school setting, where students' innate curiosity and imagination are especially evident, experiments serve as a catalyst for motivation and cognitive engagement (Holubova, 2019). They establish an environment conducive to genuine learning, wherein students encounter the thrill of discovery and the cognitive fulfillment of comprehending the physical world. Moreover, the utilization of basic, inexpensive materials–readily found in common environments–guarantees that practical experimentation remains accessible and scalable, even in resource-limited contexts. This is especially important for advancing equity in science education, allowing all students, irrespective of socio-economic status, to engage meaningfully in inquiry-based learning (Farida et al., 2018).

This longitudinal study highlights that fully harnessing the pedagogical potential of hands-on experiments necessitates overcoming various obstacles. Structural elements, including insufficient laboratory facilities and time limitations, alongside cultural considerations such as apprehensions regarding classroom management and student safety, persist in obstructing the systematic incorporation of experimental activities in numerous primary classrooms (da Silva et al., 2020). Confronting these challenges necessitates a comprehensive strategy that integrates infrastructure investment, ongoing professional development, and the fostering of a school culture that prioritizes inquiry, creativity, and active student engagement. Incorporating hands-on experimentation as a fundamental aspect of primary physics education is essential for enabling all learners to actively participate in science and cultivate the skills and attitudes necessary for informed citizenship in a scientifically intricate society (Sekarini & Arty, 2019).

HISTORICAL CONTEXT OF EXPERIMENTAL PHYSICS TEACHING IN GREEK PRIMARY EDUCATION

The year 2001 represents a pivotal moment in the instruction of physics within the Greek primary education system. Before this period, the primary instructional model in Greek primary schools was predominantly textbook-oriented, with minimal focus on experiential or inquiry-based methods. The official science textbook of that era, "investigating the natural world" ["erevno ton physiko kosmo"], offered minimal explicit endorsement for experimental activities, and the dominant curriculum regarded experimentation as ancillary rather than fundamental to science education. Educators, frequently deficient in specialized training in experimental methodologies and adequate laboratory resources, tended to depend predominantly on expository instruction and verbal elucidations. This method provided minimal opportunity for cultivating students' active participation in scientific inquiry or for enhancing practical investigative skills (Kotsis, 2001).

The curricular reform of the early 2000s commenced a gradual transition towards more experimental and inquiry-based science instruction. The implementation of a multiple-textbook policy and the subsequent adoption of a standardized physics textbook series from 2005 onwards indicated a renewed focus on systematically incorporating experimental activities into classroom practices. The updated curriculum frameworks explicitly advocated for the utilization of experiments to enhance conceptual comprehension and inquiry abilities. Simultaneously, an expanding corpus of educational research has underscored the advantages of experiential learning and the significance of involving students in practical science activities (Kotsis, 2005; Duit & Tesch, 2010). These developments presented both opportunities and challenges for Greek primary educators, many of whom were required to modify their instructional practices to conform to changing pedagogical expectations.

Notwithstanding the favorable intentions underlying curricular reform, the transition to the extensive implementation of experimental teaching was neither prompt nor uniform among schools. Structural obstacles, such as restricted access to laboratory facilities, insufficient equipment, and time limitations, persistently hindered the execution of practical activities. Moreover, numerous educators expressed individual uncertainties about executing experiments, referencing a deficiency in confidence regarding their experimental competencies and apprehensions related to classroom management and safety. The absence of systematic professional development opportunities specifically aimed at experimental science instruction further intensified these challenges. As a result, the degree of integration of experimental methods into primary physics instruction varied markedly among schools and individual educators.

This longitudinal study seeks to systematically record the evolution of experimental physics instruction in Greek primary education over a 23-year span (2001-2024), with a particular emphasis on the region of Ioannina. The study offers a unique diachronic perspective on the changing role of experimentation in primary science classrooms by examining shifts in teachers' practices, perceptions, and attitudes across four consecutive survey waves. Furthermore, the findings provide significant insights into the enduring obstacles that impede the complete implementation of an inquiry-based approach to science education within the Greek context.

RESEARCH

This study aims to examine the progression of experimental physics teaching methodologies in Greek primary education from 2001 to 2024. This study specifically seeks to examine alterations in the frequency and nature of teachers' utilization of experiments in the classroom, transformations in their attitudes towards experimental pedagogy, and the obstacles that persist in obstructing the comprehensive adoption of inquiry-based science instruction. Significant attention is directed towards comprehending how systemic factors–such as curriculum reforms, textbook modifications, and professional development opportunities–have impacted teachers' practices and perceptions over time. This study provides a nuanced understanding of the advancements and challenges in achieving effective experimental science teaching in primary education through a longitudinal analysis of these dynamics.

The study employs a comparative longitudinal design by administering the identical survey instrument at four separate time intervals. Data collection took place in the Ioannina region of Greece at intervals of five years or more, aligning with significant instances of curricular and instructional modification. The four survey waves occurred in 2001, 2005, 2008, and 2024, enabling the study to identify both medium-term and long-term trends in experimental teaching practices. The study exclusively examines practicing primary school teachers, offering direct insights into the realities of classroom practice as experienced by the educators.

Participant recruitment was executed on a voluntary basis, with invitations disseminated via established educational networks. This method guaranteed that the sample encompassed a diverse array of educators with varying levels of experience, training backgrounds, and educational environments. The total number of participants in each survey wave was as follows: 216 teachers in 2001 (during the final year of the pre-reform textbook investigating the natural world) (Kotsis, 2001), 206 teachers in 2005 (after the implementation of the multiple-textbook policy and the new national curriculum) (Kotsis, 2005), 102 teachers in 2008 (during a period of curricular stability with a standardized physics textbook) (Kotsis & Bassiakos, 2009), and 210 teachers in 2024 (aligned with the expected shift to inquiry-based and STEM-focused textbooks). The uniformity of the sample over time intervals strengthens the credibility of the longitudinal comparisons.

The research instrument employed in all four phases was a structured, closed-format questionnaire intended to gather quantitative data on teaching practices and qualitative insights into teachers' attitudes and perceived obstacles. The questionnaire comprised four thematic sections:

(1) the frequency of employing experimental demonstrations in physics instruction,

(2) perceived barriers to conducting experiments,

(3) the frequency of student engagement in experiments, and

(4) justifications for restricting or eschewing student-centered experimental activities.

The instrument was created based on established international literature regarding teachers' attitudes toward science instruction (Kotsis, 2001) and was tested during its initial implementation in 2001. Subsequent iterations involved minor adjustments–primarily updates to terminology to align with changes in the national curriculum (e.g., replacing outdated textbook titles and curriculum references)–while maintaining identical question structure, response scales, and construct measured. These modifications did not affect the comparability of data across the four waves. This methodological consistency improves the reliability of comparisons and facilitates rigorous longitudinal analysis.

This research design offers a unique diachronic perspective on the development of experimental teaching practices in primary physics education, a field that is still largely underexamined in empirical studies. The findings are pertinent not only to the Greek educational framework but also to global dialogues regarding the advancement of inquiry-based science education in primary schools.

It should be noted that the analysis is based on descriptive statistics rather than inferential testing. This is due to the unavailability of raw, individual-level data from earlier survey waves, which precluded the use of parametric or non-parametric tests. Nevertheless, the use of an identical survey instrument, consistent sampling strategy, and comparable participant characteristics across waves supports the reliability of observed patterns and renders descriptive longitudinal analysis an appropriate and valid method for identifying meaningful trends in educational practice over time.

FINDINGS/RESEARCH

Frequency of Use of Experimental Demonstration

The initial research question investigated the degree to which primary school educators integrate experimental demonstrations into their physics teaching. Experimental demonstrations, usually performed by the instructor at the front of the classroom, are a crucial pedagogical instrument for rendering abstract phenomena concrete and for exemplifying scientific inquiry methodologies. Although these demonstrations do not completely replace student-centered experimentation, they serve as an essential gateway for incorporating empirical observation and discourse into science instruction.

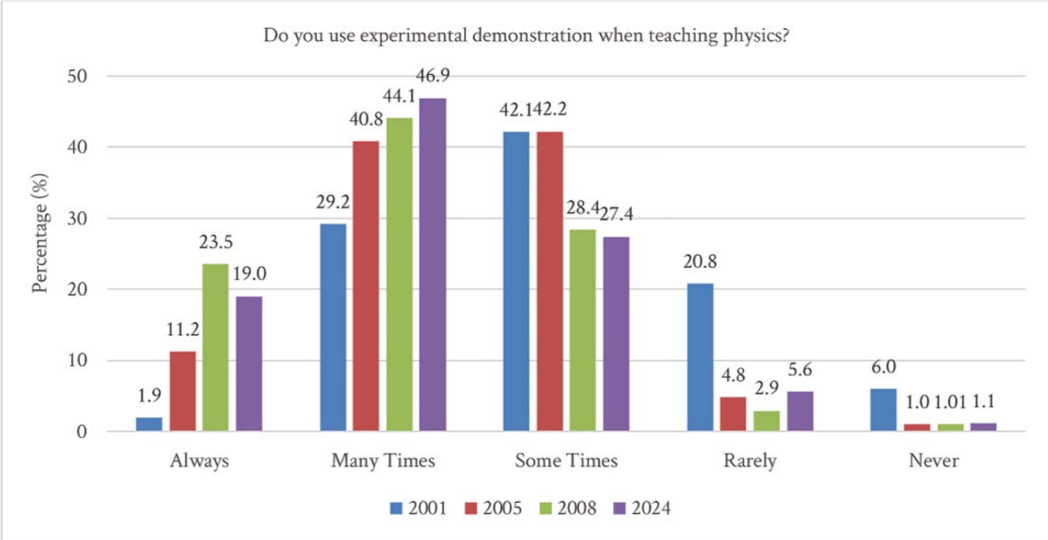

Figure 1. Teachers' responses to the question "Do you use experimental demonstration when teaching physics?" (Source: Created by the author)

The first question examines the extent to which teachers use experimental demonstrations when teaching physics. The teachers' responses are presented in **Figure 1**.

The longitudinal data indicate a significant increase in the frequency of experimental demonstrations from 2001 to 2008, followed by stabilization and a minor decline in 2024. In 2001, at the commencement of the study, merely 31.1% of educators indicated that they utilized experimental demonstrations "always" or "often" in their physics instruction, highlighting the insufficient curricular focus on practical methodologies and the concomitant absence of institutional backing. After the implementation of new curricula and updated textbooks in 2005, a significant increase was noted, with the percentage of teachers employing demonstrations "always" or "often" escalating to 67.6% by 2008. This finding indicates that curricular reforms significantly enhanced the implementation of experimental methods in primary classrooms.

In the 2024 wave, the overall incidence of experimental demonstrations remained notably high, with 46.9% of teachers indicating "often" usage, although the percentage reporting "always" experienced a slight decrease compared to 2008. The slight reduction in "always" responses between 2008 and 2024 may reflect broader systemic pressures in the post-COVID-19 era, including intensified curriculum coverage to address perceived learning losses, teacher workload increases due to digital integration initiatives, and persistent infrastructural gaps. Such factors may have tempered the initial momentum generated by mid-2000s reforms. This minor reduction may indicate the emergence of external constraints, such as ongoing infrastructural limitations and competing curricular demands, which have mitigated the initial momentum of reform. Nonetheless, the findings reveal that experimental demonstrations have become a widely integrated component of physics instruction in Greek primary education, in stark contrast to their previously peripheral status at the onset of the study period.

These patterns underscore the intricate interaction among policy initiatives, curricular frameworks, and classroom dynamics. Although top-down reforms can effectively facilitate pedagogical transformation, enduring advancement relies on overcoming structural obstacles and delivering continuous professional support to educators. The persistent use of experimental demonstrations in most classrooms indicates that numerous educators acknowledge their significance in improving students' comprehension of scientific concepts and promoting engagement with the inquiry process.

Barriers to Teachers' Use of Experiments

The second research question examined the barriers that primary school teachers identify as hindering their capacity to integrate experimental activities into their physics teaching. The teachers' responses are presented in **Figure 2**.

Comprehending these obstacles is essential for guiding policy and professional development initiatives designed to enhance the broader and more effective implementation of experimental teaching methodologies. The longitudinal analysis indicates that although some constraints have lessened over time, others persist and continue to influence the practical realities of classroom science instruction.

Throughout all four survey waves, the predominant obstacle identified was the deficiency of laboratory equipment and suitable instructional space. This issue reached its zenith in 2005, with 81.6% of educators citing insufficient resources as a significant impediment and persisted at a high level in 2024 at 73.2%. The longitudinal trends depicted in **Figure 2** illustrate that the lack of laboratory equipment and suitable instructional space has remained the most significant barrier throughout the study period. This concern reached its highest level in 2005, when 81.6% of teachers identified it as a major impediment, coinciding with the early implementation stage of the new curriculum, before substantial infrastructure investments had been made. Although a modest improvement is evident in 2024, with the percentage dropping to 73.2%, the persistence of such high values underscores the enduring nature of this structural challenge. This sustained barrier suggests that, despite policy reforms and increased curricular emphasis on experimentation, many primary schools have yet to receive adequate resources or designated spaces for hands-on science activities. The data aligned with international research indicating that without consistent infrastructure support, inquiry-based approaches remain difficult to implement systematically in everyday classroom practice. Notwithstanding national initiatives to enhance science curricula and advocate for inquiry-based learning, numerous Greek primary schools remain devoid of specialized science laboratories or adequate

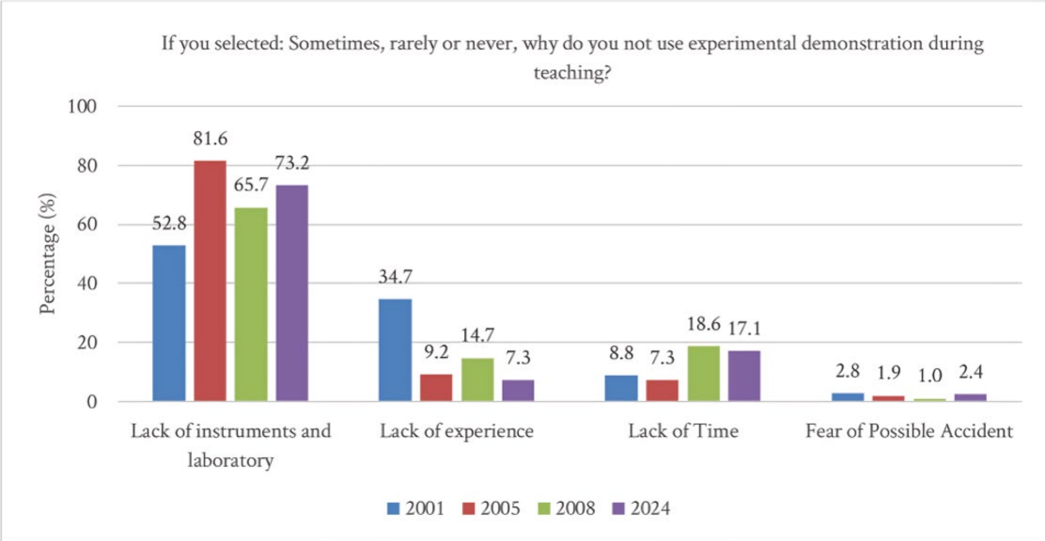

Figure 2. Teachers' responses to the question "If you selected: Sometimes, rarely, or never, why do you not use experimental demonstration during teaching?" (Source: Created by the author)

experimental materials. Educators frequently rely on improvisation with commonplace items or perform demonstrations instead of engaging in fully interactive experiments. This finding aligns with global research demonstrating that resource constraints are a substantial structural barrier to the execution of hands-on science instruction, especially in environments with inadequate funding for laboratory facilities (Josey et al., 2018).

Encouragingly, the absence of personal experience or confidence in conducting experiments exhibited a distinct decline throughout the study period. In 2001, 34.7% of educators indicated that their own limited experimental proficiency deterred them from integrating hands-on activities. By 2024, this percentage had decreased to merely 7.3%. This transition indicates that professional development programs and heightened curricular focus on experimental teaching may have enhanced teachers' confidence and competencies in this area. Nonetheless, a significant number of educators persist in voicing concerns about their capacity to effectively oversee experimental activities, especially those requiring active student involvement (see Section 4).

A significant barrier that has emerged is the deficiency of instructional time. In 2001, merely 5.5% of educators recognized this issue, whereas the percentage increased to 17.1% by 2024. This increase signifies overarching systemic pressures, such as curriculum congestion, administrative obligations, and the requirement to address an expanding array of content areas within constrained instructional time. Consequently, even educators who appreciate experiential teaching may struggle to dedicate adequate time for the planning and execution of substantive hands-on activities. This discovery underscores the necessity for curricular and scheduling reforms that explicitly prioritize time for inquiry-based learning.

Ultimately, safety concerns persisted as a relatively insignificant yet consistent factor. In 2024, merely 3.4% of educators identified the apprehension of possible accidents as an impediment to executing teacher-led demonstrations. This indicates that although safety concerns are not a principal deterrent for demonstrations, they may assume greater importance in the context of student-led experimentation. The data suggest that although advancements have been achieved in overcoming specific teacher-related obstacles, structural limitations and systemic pressures persist as significant impediments to the comprehensive incorporation of experimental teaching in primary science education.

Frequency of Student Participation in Conducting Experiments

The third research question investigated the degree to which students are afforded opportunities to actively participate in conducting experiments during physics lessons. The teachers' responses are presented in **Figure 3**. Although teacher-led demonstrations effectively illustrate physical phenomena and model scientific reasoning, direct student engagement in experimental activities is deemed crucial for cultivating profound conceptual understanding, inquiry skills, and favorable attitudes toward science (Duit & Tesch, 2010; Josey et al., 2018). Student-centered experimentation enables learners to formulate inquiries, evaluate hypotheses, gather data, and derive conclusions–experiences that closely resemble professional scientific practices and enhance scientific literacy.

The longitudinal data indicate a significant and promising rise in student engagement in experimental activities over the 23-year period analyzed. In 2001, merely 7.2% of educators indicated that they "always" or "often" permitted their students to perform experiments independently during physics instruction. This low baseline indicates the conventional didactic approach to primary science education during that period, characterized by minimal student engagement, primarily restricted to passive observation. Subsequent to the curricular reforms of the mid-2000s and an increasing focus on inquiry-based learning, the percentage of teachers enabling regular student experimentation consistently increased, attaining 54.2% in 2024. This significant transition indicates a widespread cultural transformation in primary science education, with numerous educators increasingly acknowledging the importance of active student participation in the experimental process.

Nonetheless, it is crucial to acknowledge that in 2024, approximately 45% of educators still indicated permitting student experimentation only "sometimes," "rarely," or "never." This suggests that, despite notable advancements, the shift to a wholly inquiry-based

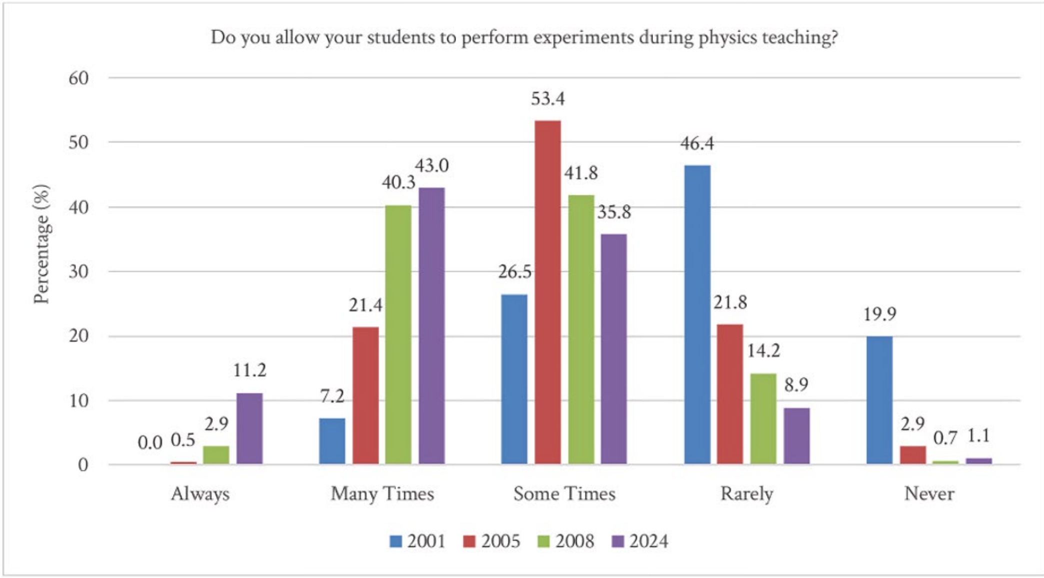

Figure 3. Teachers' responses to the question "Do you allow your students to perform experiments during physics teaching?" (Source: Created by the author)

model of science instruction is still unfinished. Multiple factors are likely responsible for this incomplete implementation. As outlined before, constraints related to equipment, time, and instructional space persistently limit the systematic integration of hands-on activities into teaching. Furthermore, certain educators may still perceive themselves as inadequately equipped to effectively oversee student-centered experimentation, especially in larger or more heterogeneous classrooms.

The data indicate that modifications in teacher attitudes have significantly contributed to enhancing student participation. As professional development opportunities and curricular guidelines have increasingly emphasized the pedagogical advantages of active learning and student inquiry, numerous educators have become more inclined to explore student-centered methodologies. Nonetheless, continuous support–comprising ongoing training, peer collaboration, and access to practical resources–will be essential to further integrate these practices and guarantee that all students consistently engage in authentic scientific inquiry.

Barriers to Student Participation in Conducting Experiments

The fourth research question aimed to identify the obstacles that inhibit or dissuade teachers from permitting students to actively engage in experiments during physics lessons. The teachers' responses are presented in **Figure 4**.

Although student-centered experimentation is extensively promoted in science education literature for its ability to enhance inquiry skills, conceptual comprehension, and scientific dispositions (Duit & Tesch, 2010), its practical application frequently encounters considerable obstacles in primary classrooms. Comprehending these obstacles is crucial for formulating targeted strategies to assist educators in embracing more inquiry-based methodologies.

Throughout all four survey waves, the most frequently mentioned barrier to student engagement in experimentation was the apprehension of accidents. In 2008, this issue reached its zenith, with 52.9% of educators reporting that apprehensions regarding student safety constrained their readiness to conduct hands-on experimentation. Despite a decrease to 41.6% in 2024, this figure continues to represent the most significant obstacle in the latest data. This ongoing concern highlights both actual and perceived dangers related to students' management of experimental materials and equipment, especially in classrooms devoid of adequate laboratory facilities or supervision protocols. It underscores the necessity for improved teacher training in safety management during experimental activities, alongside institutional support for creating secure and adequately equipped environments for inquiry-based learning. The pronounced peak in 2008 (52.9%) coincides with heightened national discourse on school safety following widely publicized incidents in other subject areas, which may have increased teacher caution regarding student-handled experiments. This trend moderated by 2024, potentially reflecting improved safety awareness and teacher training.

A notable discovery is that the deficiency of teacher experience has substantially lessened as an impediment over time. In 2001, numerous educators conveyed diminished confidence in their capacity to facilitate student-centered experimentation. By 2008 and 2024, this issue had significantly diminished, with less than 5% of educators identifying it as a primary impediment. This favorable trend indicates that professional development initiatives and enhanced exposure to inquiry-based teaching models have contributed to the enhancement of teacher proficiency in conducting experimental activities.

Nonetheless, inadequate instructional time and insufficient material resources persist as significant obstacles. Numerous educators indicated that the demands of addressing an extensive and rigorous curriculum afford minimal opportunity for the design, preparation, and execution of student-centered experiments. Furthermore, the absence of suitable equipment and consumable materials–an issue intricately linked to overarching funding and infrastructure limitations–restricts the viability of consistent hands-on activities in numerous classrooms. Systemic issues necessitate resolution via policy initiatives and resource distribution for inquiry-based science teaching to transition from an exception to the standard in primary education.

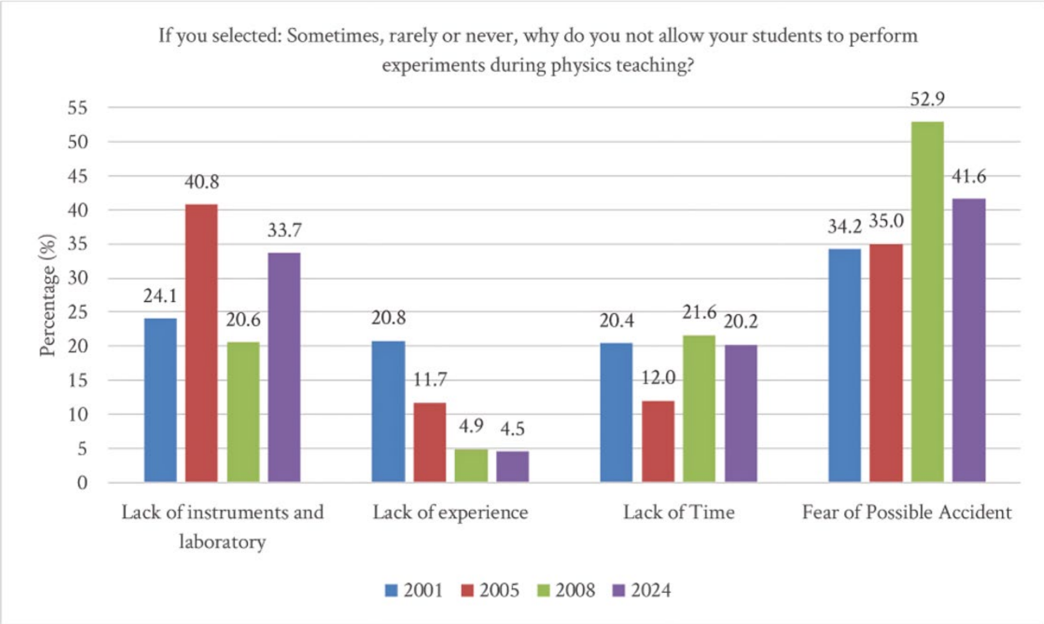

Figure 4. Teachers' responses to the question "If you selected: Sometimes, rarely or never, why do you not allow your students to perform experiments during physics teaching?" (Source: Created by the author)

The findings highlight a complex interaction of pedagogical, structural, and cultural factors influencing the execution of student-centered experimentation. Although educators' personal preparedness to implement these practices has enhanced, external limitations–especially concerning safety, time, and resources–persist in obstructing their complete incorporation into routine classroom activities. Overcoming these obstacles necessitates a collaborative approach that includes curriculum reform, professional development, infrastructure investment, and the cultivation of a school culture that prioritizes and endorses inquiry-based science education.

While this study documents notable changes in the frequency and nature of experimental teaching over time, it is based on descriptive analysis rather than inferential statistics. Due to the lack of access to raw, individual-level data from earlier survey waves, statistical significance testing between successive applications could not be performed. However, the consistency of trends observed across all four waves, coupled with a uniform research instrument and comparable sample characteristics, offers robust qualitative support for interpreting meaningful shifts in teachers' practices and perceptions. Future research could complement these findings through statistical modeling or multivariate analysis based on newly collected datasets.

DISCUSSION

This longitudinal study's findings offer significant insights into the changing dynamics of experimental physics instruction in Greek primary education over the last twenty years. The starting point of this longitudinal study coincides with a critical pedagogical shift in the field of science education. During the 1990s and early 2000s, the focus was primarily on conceptual understanding through constructivist models of teaching (Driver et al., 1994; Osborne & Freyberg, 1985), aiming at addressing students' alternative conceptions and gradually building scientific knowledge. However, from the mid-2000s onward, both internationally and within Greek educational policy, there has been a clear shift toward inquiry-based approaches (inquiry-based science education), where the experiment is not merely used for demonstration or confirmation of theories, but as a means of formulating questions, testing hypotheses, and constructing knowledge (Abd-El-Khalick et al., 2004; Harlen, 2013). The revised science curriculum (Pedagogical Institute, 2003) introduced the concept of inquiry, albeit with limited classroom implementation, while the 2011 curriculum (Institute of Educational Policy, 2011) explicitly adopted the model of the scientific method (observation-hypothesis-experiment-conclusion), promoting action-based and discovery-oriented teaching scenarios. This pedagogical shift appears to be reflected in the findings of the present study: the significant increase in the use of experimental activities by teachers after 2005, as well as the greater involvement of students, may be the result of this theoretical and practical transition. In 2024, with the draft of a new curriculum based on STEM and inquiry-based practices (Kotsis et al., 2023), this trend seems to be further reinforced, although its full consolidation remains a challenge. Therefore, the study's findings are not merely a reflection of teachers' experiences but also an expression of the evolving pedagogical paradigms that dominated the period from 2001 to 2024. The strengthening of experimental practices is likely connected to this systemic and theoretical shift, enhancing the interpretative value of the results within the broader context of educational transformation.

The findings underscore significant advancements and ongoing obstacles. Positively, there has been a discernible cultural shift towards enhanced acknowledgment of the significance of experimental pedagogy (Sharma, 2021). The heightened occurrence of teacher-led demonstrations and student-centered experimentation indicates a greater adherence to international best practices in science education, which prioritize active learning, inquiry processes, and the cultivation of scientific thinking skills (Josey et al., 2018). The data indicate that teachers' attitudes and self-confidence towards experimental teaching have enhanced over time, reflecting the beneficial effects of curricular reforms, professional development, and the progression of pedagogical discourse.

Nonetheless, the study indicates that substantial systemic obstacles persist. The primary issues are infrastructural deficiencies, particularly the absence of specialized laboratory facilities and adequate equipment, coupled with time limitations resulting from a congested curriculum. These findings align with extensive international evidence demonstrating that structural conditions significantly influence the viability of inquiry-based science instruction in primary education (Railbolt et al., 2019). Moreover, apprehensions regarding safety persist in constraining teachers' willingness to engage students directly in experimental activities, notwithstanding the diminishing levels of personal pedagogical insecurity. This underscores the necessity for focused interventions in teacher training, prioritizing safe classroom experimentation, and in school infrastructure to create environments that facilitate student inquiry.

Moreover, the data indicate that although the updated curricula and textbooks of the mid-2000s significantly facilitated experimental teaching, the subsequent progress may have diminished in recent years. The minor reduction in the prevalent use of demonstrations and the persistent irregular adoption of student-centered experimentation suggest that systemic support for inquiry-based teaching must be maintained and strengthened over time. In the absence of sustained investment in professional development, curriculum design, infrastructure, and resource allocation, there exists a potential for initial advancements to stagnate or deteriorate (Haagen-Schützenhöfer & Joham, 2018).

The findings highlight the intricate and evolving characteristics of pedagogical change. Advancing experimental physics instruction in primary education necessitates more than mere curriculum modifications or the introduction of new textbooks; it demands a comprehensive and enduring strategy that encompasses the interconnected areas of educator proficiency, institutional culture, resource availability, and overarching policy structures. This study's documentation of the Greek experience provides significant insights for both national educational stakeholders and the broader international community involved in promoting inquiry-based science education.

Taken together, these findings underscore both the progress achieved and the systemic barriers that remain in the pursuit of fully inquiry-based physics teaching in primary education. As such, they call for renewed attention to the structural, cultural, and professional factors shaping science teaching practice. The following conclusions distill key insights and implications arising from this longitudinal study.

CONCLUSION

The evolving patterns documented in this study point to important lessons for educators, policymakers, and curriculum designers alike. Addressing the persistent challenges and sustaining the gains achieved will require coordinated efforts at multiple levels of the education system. The conclusions below highlight actionable insights and future directions emerging from the longitudinal evidence. This comparative longitudinal study provides a unique diachronic perspective on the development of experimental physics instruction in Greek primary education over a span of 23 years. The results illustrate a complex landscape of advancement and persistent difficulties. The data unequivocally indicate a transition towards more experimental and inquiry-based teaching methodologies. The frequency of teacher-led demonstrations and the extent of student engagement in hands-on experiments have significantly risen since 2001, indicating an increasing acknowledgment among educators of the pedagogical importance of experiential learning in science education. These modifications correspond with global trends and affirm that effectively structured curricular reforms–when paired with adequate professional development–can promote significant transformations in teaching methodologies.

The study concurrently emphasizes enduring obstacles that impede the complete implementation of inquiry-based physics instruction in primary education. Structural constraints–particularly deficient laboratory facilities, restricted equipment, and inadequate instructional time–persist as substantial impediments. Furthermore, apprehensions regarding student safety persist in influencing educators' choices about the extent of student participation in experimental activities. Although educators' confidence in executing experiments has increased, establishing genuinely inquiry-rich classroom environments necessitates systemic interventions that surpass individual teacher training.

The Greek experience outlined herein highlights several significant implications for policy and practice, many of which align with global challenges in promoting science education reform. Firstly, continuous investment in educational infrastructure is crucial to facilitate experiential science instruction. Secondly, professional development for educators must extend beyond isolated training sessions to offer continuous, practice-oriented learning opportunities that enhance both pedagogical and classroom management competencies for inquiry-based instruction. Third, curricular frameworks must explicitly designate time for experimental activities within the school timetable, ensuring that inquiry is not subordinated to competing priorities. Ultimately, cultivating a school culture that prioritizes and endorses experimentation, while promoting risk-taking and innovation in pedagogy, is essential for maintaining advancement.

In summary, advocating for experimental pedagogy in primary physics education is a multifaceted yet attainable objective. It necessitates synchronized efforts across various tiers of the education system and a sustained commitment to integrating inquiry-based methodologies as an essential element of science education. This study's evidence indicates that, despite ongoing challenges, positive change is achievable when curricular vision, professional development, and institutional support are harmonized. These lessons are pertinent not only to Greece but to all educational systems aiming to develop scientifically literate citizens capable of navigating the complexities of the contemporary world.

The findings of this longitudinal study offer several important policy lessons for the advancement of experimental and inquiry-based physics teaching in primary education–lessons that resonate not only within the Greek context but also across European education systems facing similar challenges. First and foremost, the persistence of structural barriers such as inadequate laboratory facilities and insufficient access to experimental materials underscores the need for sustained public investment in the physical infrastructure of primary schools. Equipping classrooms with basic, age-appropriate experimental kits and creating flexible spaces for hands-on activities are essential prerequisites for making inquiry-based teaching a realistic everyday practice rather than an occasional enrichment activity.

Second, the increasing time pressures reported by teachers highlight the importance of curriculum design that explicitly prioritizes experimental and inquiry-based learning. Policymakers should ensure that revised curricula allocate sufficient protected time for hands-on science activities, rather than crowding out such opportunities through excessive content coverage or competing administrative demands.

Third, while professional development has clearly contributed to improving teachers' confidence and competence in conducting experiments, the study suggests that further efforts are needed to address remaining concerns about classroom safety and the facilitation of student-centered experimentation. Policy initiatives should promote ongoing, practice-based teacher learning communities where educators can share strategies, observe exemplary practices, and receive mentoring on managing inquiry-rich classrooms effectively and safely.

Fourth, the cultural dimension of school environments must not be overlooked. Building a culture of inquiry requires not only technical resources and teacher training but also leadership at the school level that values experimentation, tolerates productive risk-taking, and fosters collaborative reflection on teaching practices. Policymakers should therefore support school leadership development programs and encourage the creation of networks of innovative practice across schools.

Finally, longitudinal monitoring of pedagogical change, as conducted in this study, should be institutionalized within national education evaluation systems. By systematically tracking the evolution of teaching practices, policymakers can obtain timely feedback on the effectiveness of reforms and identify areas requiring further support. The Greek experience demonstrates that progress is possible but that it must be continuously supported, monitored, and adapted to local contexts if inquiry-based science education is to become a lasting reality in primary schools.

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