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Impact of Spaced Learning on Educational Outcomes in Science Teaching

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Abstract

Recent research highlights the importance of effective teaching methodologies to enhance scientific learning from the earliest years of schooling. The present study investigates the effects of the *Spaced Learning (SL)* methodology in science education in Italian primary schools, with particular attention to scientific knowledge and students' scientific reasoning skills. The study involved 401 third- and fourth-grade pupils (aged 8–11) from three primary schools in Palermo, Italy, during the 2024/2025 school year. A quasi-experimental design was adopted, with classes assigned to an experimental group that adopted SL or to a control group that followed traditional teaching. The intervention lasted seven months and was supported by continuous teacher training and collaboration with university researchers. The data were collected through a pre-test/post-test questionnaire developed and validated by experts in physics education. The tool assessed the students' general scientific reasoning skills through multiple-choice items inserted in everyday life contexts. Descriptive statistics were calculated and between-group comparisons were made by Student's t-test or Welch's t-test when the assumption of homogeneity of variances was not met. The results indicate that students exposed to the SL methodology achieved higher post-test scores than those who received traditional education, suggesting a positive effect of time-distributed, movement-integrated learning on science learning outcomes. Such results support the effectiveness of SL as a promising teaching approach to promote meaningful and lasting scientific learning in primary school.

Keywords: Spaced Learning; primary school; scientific reasoning; cognitive engagement; physical activity

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1. Introduction

The recent literature underlines (Bjerknes et al., 2024; Mascia & Wilson, 2026) with increasing evidence the importance of learning science from early childhood. Early exposure to scientific content and phenomena provides children with the opportunity to cultivate their innate curiosity and explore the natural world (Eshach & Fried, 2005). In addition, the acquisition of fundamental scientific concepts supports the development of problem-solving skills and fosters a deeper understanding of reality (Hong & Diamond, 2012).

Sciences can be conceptualized as a way of knowing and investigating the world. The development of scientific thinking allows students to reason critically, make informed decisions, and seek evidence-based explanations. Thus, science learning goes beyond the mere acquisition of factual knowledge, as it also promotes logical reasoning, the formulation of meaningful questions, and the ability to deal with problems of everyday life (Capps & Crawford, 2013; Carin et al., 2005; Mulyenı et al., 2019).

The teaching and learning of science are complex and multidimensional processes, influenced by a plurality of factors. In this perspective, scientific competence is articulated in closely interrelated dimensions, including the understanding of the nature of science and technology, the acquisition of fundamental scientific concepts, the development of scientific process skills (SPS), the awareness of the relationships between science, technology, society and the environment, as well as the maturation of psychomotor skills, values and attitudes proper to scientific practice (Monteyne, 2004).

Scientific process skills include cognitive and operational skills that enable students to collect, organize, and interpret information, as well as to predict and explain natural phenomena (Carin et al., 2005). These skills, which reflect the skills mobilized by scientists in the context of scientific inquiry (Bentley et al., 2007; Martin, 1996), are generally divided into basic skills and integrated skills. The former includes observation, classification, measurement, inference, prediction, and communication; the latter includes, on the other hand, the identification and control of variables, the formulation of hypotheses, the interpretation of data, the operational definition of concepts, the conduct of experiments, and the construction of models.

The present study examines in particular two central dimensions of scientific learning: the acquisition of scientific knowledge and students' understanding of the Nature of Science (NOS). Both are fundamental for the development of scientific literacy starting from primary school.

The Nature of Science refers to the fundamental principles and ideas that define science both as a way of knowing and as a body of knowledge (Satria, 2018; Satria & Sari, 2018). It includes the values and assumptions inherent in scientific knowledge and the processes through which that knowledge is generated (Lederman, 1992). This perspective encompasses the empirical foundation of science, its creative and imaginative aspects, the influence of social and cultural contexts, and the provisional character of scientific knowledge (Lederman et al., 2002). Consequently, NOS can be understood as an epistemological framework that highlights science as a systematic process of knowledge construction based on specific assumptions and values (Lederman & Lederman, 2004).

Research has consistently shown that inquiry-based learning contributes significantly to students' acquisition of scientific knowledge, the development of scientific process skills, and a more conscious understanding of the empirical nature of science (Mulyenı et al., 2019; Pratt & Hackett, 1998). Inquiry can be defined as the process of searching for information through the formulation of questions (Bentley et al., 2007) and reflects an approach to exploration consistent with the practices of scientists (Yager & Akcay, 2010). Through inquiry-based learning, students are actively involved in asking questions, testing hypotheses, and constructing explanations (Ansberry & Morgan, 2010), thus promoting critical, logical, and creative thinking. For this reason, science education should adopt inquiry-centered pedagogical approaches in order to foster genuine scientific competence.

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2. Theoretical Background

Science teaching in Italy has undergone significant changes in recent decades. If for most of the twentieth century it was mainly characterized by a transmissive and traditional approach, contemporary perspectives aim to cultivate in students a scientific attitude towards reality, stimulating critical thinking and curiosity (Harlen, 1999; Pratt & Hackett, 1998). In contemporary educational research, science teaching is increasingly conceived not simply as a transmission of disciplinary content, but as a process aimed at promoting scientific skills, critical reasoning, and the ability to apply knowledge to real problems and societal challenges (Bo, 2025).

In Italian primary schools, the science curriculum follows the National Curriculum Guidelines issued by the Ministry of Education and Merit. The sciences fall within the broader disciplinary area of "Mathematics and Science" and address several fundamental areas, such as the observation of the natural world, the study of living organisms, the environment, materials, and physical phenomena. The Guidelines underline the role of science as a means of developing critical thinking, curiosity, and understanding of the natural world, essential elements in the education of future citizens. A practical and experimental approach is strongly encouraged, allowing students to actively participate through experiments, direct observation, and laboratory activities.

Despite these recommendations, this change in perspective is not always reflected in classroom teaching practice. Laboratory activities are often limited to the verification of results predicted by theoretical laws, rather than being used as tools of empirical investigation, thus resulting in a more "verification-based" than "discovery-based" approach.

The results of the OECD surveys (Bo, 2025) offer an overview of the scientific skills of fifteen-year-old students, providing valuable insights into the effectiveness of science education and study. Scientific literature is defined as the ability of students to engage with scientific issues and ideas as reflective citizens.

Unfortunately, the results of PISA 2023 paint a worrying picture of the study of science both globally and in Italy (OECD PISA, 2023). In science, Italy scored 477, below the OECD average, with a performance comparable to that of Lithuania, Portugal, Croatia, Norway, Turkey, and Vietnam (OECD PISA, 2023). At the international level, this places Italy between 22nd and 38th place among all participating countries, and between 18th and 31st place if only OECD countries are considered. Significant regional disparities also persist in Italy, with a difference of 68 points between the macro-areas with the highest and lowest results (North-West: 507; South: 439). In addition, the differences between types of schools remain marked, with high school students obtaining significantly higher average scores in science than those in technical and vocational institutes (Bo, 2025).

However, some positive signs also emerge from the report. Compared to 2018, Italian students showed a statistically significant improvement of 9 points, along with an increase of 1.5 percentage points in the share of high-performing students (Bo, 2025).

The persistent disparities between geographical areas, types of school, and the difficulties often encountered by teachers in teaching science highlight the need for a critical reflection on teaching methodologies, starting from primary school. There is an urgent need to adopt teaching approaches that respond to students' learning needs and promote meaningful and authentic scientific learning experiences.

In the light of these considerations, the present study aims to examine the effectiveness of *the Spaced Learning* (SL) methodology in the field of science in Italian primary schools, with reference to its impact on the acquisition of scientific knowledge and on the development of students' scientific reasoning skills. In this perspective, the SL is configured as an innovative methodology, able to actively involve students in the learning process and to

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respond to the needs of scientific investigation, widely recognized as the foundation of the development of scientific competence.

Second Year of AMIS Program: Spaced Learning with Motion-Based Intervals

During the second year of the AMIS program, the intervention was consolidated and systematically implemented in primary school classes by adopting SL as a reference teaching framework and integrating it with movement-based intervals (Anello & Ferrara, 2024). The instructional sequence was organized into repeated and distributed learning inputs, interspersed with brief moments of physical activity not directly related to the contents of the lesson, to sustain prolonged attention, facilitating consolidation processes, and promoting the active involvement of students during the session. Within this model, scientific topics were addressed through structured cycles of presentation and guided processing, while motor intervals served as planned pauses, designed to restore attention and reduce cognitive fatigue (Giarratano et al., 2025). The AMIS program was conceived as a multi-year educational and research initiative aimed at exploring innovative teaching strategies for primary school learning, with particular attention to the integration of movement, active methodologies, and inclusive educational practices. Within this broader framework, the program investigated how structured pedagogical approaches could support students' attention, engagement, and learning outcomes in authentic school contexts. The present study is situated within the second year of the AMIS program and focuses specifically on the implementation of Spaced Learning integrated with motion-based intervals in primary science education. In this phase, the intervention was designed to examine whether a structured sequence of repeated instructional inputs, alternated with active motor pauses, could support scientific learning outcomes and students' engagement during classroom activities.

The inclusion of movement-based pauses was not intended merely as a moment of interruption, but as a pedagogically meaningful component of the intervention. From a neuroeducational perspective, physical activity may support learning by enhancing attentional regulation, executive functioning, and cognitive readiness, all of which are relevant for processing and consolidating new information. Moreover, the embodied cognition framework suggests that cognition is not separated from bodily experience, but is closely connected to perception, action, and movement (Paloma, 2017). In this sense, active breaks may contribute to creating a more favourable learning condition than passive rest alone, because they combine cognitive disengagement with bodily activation. Although the present study did not directly measure neurocognitive mechanisms, the use of motor-based intervals was theoretically grounded in the relationship between physical activity, attention, executive functions, and memory processes (Paloma, 2017). The implementation of the second year of AMIS, therefore, represents an application context in which the principles of SL are carried out in daily school practice through the intentional alternation of cognitive and motor phases.

3. Materials and Methods

The study was conducted in three primary schools and involved a total of 401 pupils during the 2024/2025 school year.

The experimental intervention lasted seven months, from November 2024 to May 2025. During this period, teachers participated in specific training activities and received continuous support from experienced university researchers. At the same time, teachers provided systematic feedback on the classroom implementation of the proposed methodology. Although SL activities were carried out directly by curriculum teachers, the research framework was based on a collaborative approach, aimed at mutual exchange and enrichment between school and university.

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The scientific contents addressed during the intervention were selected by disciplinary experts, who also designed a specific evaluation questionnaire to verify the effectiveness of the teaching methodology.

In line with the research hypothesis, it was expected that the application of SL to scientific content in the third and fourth grades of primary school could promote and enhance students' learning outcomes in the scientific field. All participants were minors; therefore, written informed consent was obtained from their parents or legal guardians, and assent was obtained from the pupils before participation. The study was approved by the Institutional Ethics Committee of the University of Palermo and was conducted in accordance with the Declaration of Helsinki (approval no. 183/2023—n. 195114-2023).

3.1. Research Design

The study adopted the SL model (Anello & Ferrara, 2024), focusing on learning processes structured by temporal distancing and interspersed with motor activities. The teaching activities were designed and implemented specifically in the areas of text comprehension, grammar, mathematical problem solving, and scientific conceptualization. These activities were systematically integrated with moments of physical activity lasting about ten minutes, during which the students suspended their curricular tasks to devote themselves to motor exercises and interactive games.

The implementation of Spaced Learning in the primary school context was based on a shared and well-structured planning process, including the definition of the teaching phases and their timing. This organizational framework has proved effective in supporting the construction of a student-centered educational path and in ensuring consistency between methodological choices and educational objectives.

The methodological framework underlying the intervention integrated *Merrill's First Principles of Instruction* (Merrill, 2002), explicitly shared with teachers to guide the design of learning activities. These principles included: the presentation of problematic and challenging situations (*problems*), the activation of prior knowledge (*activation*), the demonstration of procedures and strategies (*demonstration*), the application of the acquired knowledge in different contexts (*application*), and the integration of learning in meaningful and authentic real-life contexts (*integration*).

This instructional approach has supported the design of engaging and meaningful learning experiences and has contributed to the development of stable and lasting skills in the linguistic, mathematical, and scientific fields.

3.2. Participants

The study involved three primary schools located in Palermo, Italy, with a total sample of 401 students: 161 third-year pupils and 240 fourth graders, aged between 8 and 11 years. The schools were selected by non-probability sampling, based on their willingness to participate in the study and the presence of established inclusive educational practices.

The classes were assigned either to an experimental group, in which the SL methodology was implemented, or to a control group, which followed traditional teaching practices. In the present study, the traditional approach refers to the ordinary curricular teaching adopted in the control groups. This approach included lessons conducted according to usual classroom practices, based on teacher explanation, guided discussion, individual or group exercises, and consolidation activities. In this condition, the teaching sequence was not reorganized according to a specific temporal spacing protocol, and no structured motor-based pauses were systematically included between the different phases of the lesson. Therefore, the main difference between the two approaches concerns the temporal organization of instruction: whereas traditional teaching follows the ordinary continuity of classroom lessons, Spaced Learning intentionally distributes learning contents across repeated instructional moments separated by active breaks.

3.3. Educational Content

Experts in physics education proposed to the participating teachers a structured set of scientific topics from which to select the content to be implemented in the classroom through the SL methodology. The selection of topics has been aligned with the National Indications for the Italian Curriculum and has been differentiated according to school level.

For the third grade, the teaching content focused on basic scientific concepts and introductory experimental practices. In particular, the following topics were addressed: the experimental method (two modules); the matter (a module); the states of matter (a module); water (two modules); air (one module); the soil (one module); and the measure (two modules).

For the fourth grade, the contents expanded towards more complex physical concepts and phenomena, with particular emphasis on quantitative reasoning and causal relationships. Topics included: matter (one module); the states of matter (one module); change of states (one module); heat and temperature (two modules); volume and its measurement, moving from non-standard to standard units (two modules); forces, including gravitational, elastic and frictional force (two modules); mass and weight (one module); levers (one module); mixtures and solutions (two modules); the water cycle (one module); the atmosphere (one module); density (two modules); the properties of water (one module); the properties of liquids (one module); the phenomena of buoyancy and sinking (two modules); and soil properties (one module).

The modular structure allowed flexibility in instructional planning and ensured consistency with the level of development of the students, supporting a gradual progression in conceptual understanding within the framework of the SL.

3.4. Instructional Design and Lesson Planning

To facilitate lesson design and sharing among teachers, a structured format was developed for the design of teaching interventions based on the SL methodology. Participating teachers were provided with a specific planning template to support the preparation and implementation of classroom activities.

The operational protocol was organized in five distinct phases, consisting of three didactic inputs and two intervals. During the first input, lasting 30 min, the teacher introduced the content being learned. This phase was followed by a ten-minute interval during which any reference to the educational content was deliberately avoided. The interval consisted of motor activities aimed at promoting cognitive disengagement through physical activation.

The second input, also lasting 30 min, involved the filming and processing of the previously introduced content. Teaching strategies varied according to the discipline and specific learning objectives. Subsequently, a second ten-minute interval was carried out, structured in the same way as the first and characterized by motor activities unrelated to the contents of the lesson.

During the third and final input, the teacher completed the teaching sequence by consolidating the initial content and providing opportunities for students to demonstrate their learning. This phase included application exercises, problem-solving situations, and moments of discussion and clarification.

Although the methodological structure was clearly defined in terms of phases and times, the model allowed for an adequate degree of operational flexibility. Teachers could adapt teaching strategies to the specific needs of their classes and to the characteristics of the disciplinary contents, thus personalizing the approach to teaching. This flexibility has fostered active learning and student interaction, while maintaining a consistent and scientifically based methodological framework.

3.5. The Questionnaire

A questionnaire was administered to students at the beginning and at the end of the didactic intervention in order to investigate the effectiveness of the SL methodology in science education. The two administrations corresponded to a pre-test/post-test design. The instrument was conceived as a curriculum-based assessment tool aimed at evaluating both students' scientific reasoning skills and their scientific content knowledge. It was composed of two sections. Section 1 focused on students' understanding of the Nature of Science (NOS) and scientific reasoning and was based on selected closed-ended items translated and adapted from a questionnaire previously validated in the literature, namely the Science-P Reasoning Inventory (OECD PISA, 2023). Section 2 focused on scientific content knowledge and included open- and closed-ended questions developed by a group of experts in physics/science education on the basis of the Italian National Curriculum Guidelines (per la Calabria, 2018).

The whole questionnaire was subjected to face-validity procedures and a priori analysis in order to identify possible ambiguities, refine item wording, and ensure coherence with the objectives of the study. The assessment tools were differentiated according to school level, with distinct versions designed for third- and fourth-grade primary students, in line with the specific curricular contents addressed during the intervention. Pre-test and post-test versions were designed to be comparable in terms of structure, content domains, and scoring procedures, in order to support the comparison of students' outcomes before and after the intervention.

The questionnaires were administered digitally and collectively in class to both experimental and control groups. Each questionnaire was divided into two sections, described below.

Section 1—Understanding the Nature of Science (NOS) and scientific reasoning (6 items).

It is based on the Science-P Reasoning Inventory (Osterhaus et al., 2021). The latter was developed for primary school pupils (8–10 years old) in order to measure children's conceptual progress in different components of scientific reasoning, such as experimentation, data interpretation and understanding of the nature of science. Only some of the items in the original questionnaire were selected, translated and adapted to the Italian context (Platania et al., 2021). The first section included multiple-choice items and short scenarios aimed at assessing: (a) the understanding of the concept of a testable hypothesis, distinguishing verifiable statements from descriptive or untestable statements; (b) the awareness of the fallibility of scientific knowledge, i.e., the possibility of error and revision of hypotheses; (c) the ability to recognize elements of a controlled experimental design, such as the comparison of conditions and the control of variables; and (d) the recognition of practices consistent with an empirical verification/falsification approach. Items were assessed with differentiated scores based on quality of response (e.g., 0/1/2 points), attributing higher scores to options that involved variable control or hypothesis testability.

The selected items were translated into Italian and subsequently subjected to a further validation process involving a small pilot group of students (Platania et al., 2021). These students ranged in age from 8 to 10 years old and came from a geographical background comparable to that of the schools that subsequently participated in the study.

To examine the validity of Section 1 and identify any critical issues in the items, such as unclear or ambiguous terminology, a face validity procedure was conducted (Jensen, 2003). Each student in the pilot group completed the questionnaire, after which a focus group was carried out. This allowed the researchers to clarify the meaning underlying the students' answers and to refine the items, accordingly, obtaining the final version of the tool used with the main sample of the research.

The items were placed in everyday life contexts and were designed to assess the general scientific reasoning skills of the students, regardless of their specific previous knowledge in different scientific fields. The questionnaire consisted of multiple-choice items, each with three answer options: one scientifically correct and two incorrect. Correct answers were scored with one point. One of the incorrect options, containing partially correct scientific elements, received 0.5 points, while the other, completely incorrect, received a score of 0.

The second section of the questionnaire differed for the third- and fourth-grade primary students. For third-grade students, the questionnaire had a total maximum score of 29.5 points and consisted of 24 items.

Section 2 (third primary students)—Knowledge of scientific content (18 items).

The second section assessed the basic knowledge of the scientific concepts addressed in the curriculum, e.g., matter and its properties, states of matter and changes of state, solutions and mixtures, soil and its layers, and properties of water and air. This section included true/false items (valued at 0.5 points), closed-ended questions on definitions and classifications (0.5–1 point), exercises requiring identification of the "foreign element" and sorting activities (0.5–1 point), as well as a short open-ended item (three characteristics of water, up to 3 points). The correction was based on an analytical grid, which allowed for partial scores when applicable.

For fourth-grade primary students, a questionnaire consisting of 13 items was administered, with a maximum score of 27 points, also divided into two sections.

Section 2 (fourth-grade primary students)—Knowledge of scientific content (7 items).

The second section assessed knowledge related to topics typically addressed in the fourth-grade curriculum, mainly related to heat and temperature and heat transfer (conduction; thermally conductive and insulating materials), as well as concepts concerning water properties, combustion, and the role of oxygen, buoyancy/volume changes, and thrust in a fluid. Items included: closed-ended questions on definitions and concepts (1 point), multiple-choice items with cumulative scoring (e.g., identification of multiple insulators/conductors, with attribution of 1 point for each correct answer and penalties for omissions according to the correction grid), and a short open-ended item (three characteristics of water, up to 3 points). The overall score was obtained by applying the relative correction grid.

For the second section of the questionnaire, a validation process was also conducted with a small group of students (Haynes et al., 1995). An a priori analysis of the students' possible responses to the questionnaire items was carried out. Following Brousseau (1997), this type of analysis supports the identification of the expected response strategies that students can adopt when faced with a problem, as well as the alternative responses that may emerge (Brousseau, 1997).

This process is particularly useful for researchers, as it allows for a more in-depth examination of the questionnaire content. Anticipating students' possible reasoning strategies can reveal weaknesses or ambiguities in items, allowing researchers to review and refine them before administration. The a priori analysis is conducted independently of direct observation, hence the term *a priori*, and provides a frame of reference for the subsequent examination of the students' actual responses to the questionnaire items.

To further strengthen the validity of the tool, the a priori analysis was conducted independently by two researchers. Subsequently, a consensus was reached through discussion, obtaining a shared and optimized final version of the questionnaire, consistent with the objectives of the study.

The pre-test was administered between November and December 2024, while the post-test was administered in May 2025.

4. Results

4.1. Data Analysis Methodology

The data were analyzed by descriptive statistical methods in order to examine the effectiveness of the teaching methodology adopted in the sciences.

In particular, the average scores obtained in the questionnaire were calculated for each group, together with the corresponding standard deviations and standard errors. The mean scores were then compared using Student's *t*-test to determine whether the observed differences between the groups were statistically significant. The relative *p-values* were calculated.

Given the presence of independent samples, the Fisher–Snedecor F test was conducted to assess the homogeneity of variances between the control group (CG) and the experimental group (EG). In cases where the assumption of equality of variances was not satisfied, the Student's *t*-test was replaced by the Welch *t*-test, which is more appropriate under conditions of unequal variances.

4.2. Data Analysis

The analysis of the data showed different trends between the third- and fourth-grade classes, as well as between the experimental group (EG) and the control group (CG).

The comparison between independent samples conducted at the pre-test (Table 1) showed no statistically significant differences between the control group (CG) and the experimental group (EG), with $p = 0.476$. The control group obtained an average score of M = 22.36 (SD = 3.46), while the experimental group achieved an average score of M = 21.93 (SD = 4.24). These results suggest that the two groups were comparable at baseline. The associated effect size was very small (Cohen's d = 0.113), further confirming that the initial difference between the two groups was negligible from a practical standpoint.

Table 1. Temporal articulation of the motor-integrated Spaced Learning session.

Macro-Phase	Phase	Duration	Description
Startup	Classroom management	15 min	Initial organization of the class, presentation of the activity and preparation of the teaching context.
Operation phase (100 min)	Input 1	30 min	Initial presentation of the learning content by the teacher.
	Range 1	10 min	Motor and movement activities unrelated to the educational content, aimed at promoting cognitive disengagement.
	Input 2	30 min	Shooting and processing of content, using differentiated strategies based on the discipline.
	Range 2	10 min	Motor activities similar to the first interval, without reference to the contents of the lesson.
	Input 3	20 min	Consolidation of content through application exercises, problem solving activities and moments of discussion.
Closure	Conclusion of the activity	5 min	Final summary, feedback and organization of subsequent activities.
Total		120 min	Total duration of the educational intervention.

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The within-group comparison for the third-primary control group (Table 2) showed no statistically significant change from pre-test to post-test, with $p = 0.116$. Mean scores decreased slightly from M = 22.36 (SD = 3.46) at the pre-test to M = 21.64 (SD = 2.82) at the post-test. This reduction was not statistically significant, indicating a relative stability of performance over time in the absence of the experimental intervention. Consistently, the effect size was small (Cohen's d = 0.177), suggesting that the observed decrease was limited in magnitude and not educationally substantial.

Table 2. Pre-test comparison of third-grade primary—CG/EG.

Third	CG			EG			Cohen's d	*p* Value
PRE	Avg 22.36	Standard Deviation 3.46	Standard Error 0.387	Avg. 21.93	Standard Deviation 4.24	Standard Error 0.472	0.113	0.476

In contrast, the experimental group (Table 3) showed a statistically significant improvement from pre-test to post-test, with $p < 0.001$. Mean scores increased from M = 21.93 (SD = 4.24) on the pre-test to M = 26.22 (SD = 2.61) on the post-test. This significant increase suggests a positive effect associated with the intervention. The effect size was large (Cohen's d = 0.837), indicating that the improvement was not only statistically significant but also meaningful in terms of educational impact.

Table 3. Pre–post third-grade primary—CG comparison.

Third-Grade	PRE			POST			Cohen's d	*p* Value
CG	Avg 22.36	Standard Deviation 3.46	Standard Error 0.387	Avg. 21.64	Standard Deviation 2.82	Standard Error 0.316	0.177	0.116

The post-test comparison between the control group and the experimental group (Table 4) showed a statistically significant difference, with $p < 0.001$. At post-test, the experimental group (M = 26.22, SD = 2.61) performed better than the control group (M = 21.64, SD = 2.82). This result further supports the effectiveness of the intervention in the third grades. The magnitude of this difference was very large (Cohen's d = 1.680), suggesting a strong practical effect of the intervention on students' post-test performance.

Table 4. Pre–post third-grade primary—EG comparison.

Third	PRE			POST			Cohen's d	*p* Value
EG	Avg. 21.93	Standard Deviation 4.24	Standard Error 0.472	Avg 26.22	Standard Deviation 2.61	Standard Error 0.29	0.837	<0.001

For the fourth grades, the pre-test comparison between the control group (CG) and the experimental group (EG), shown in Table 5 (Fourth-grade primary pre-test comparison—CG/EG), did not show statistically significant differences ($p = 0.347$). Mean scores were comparable (CG: M = 13.14, SD = 2.44; EG: M = 13.44, SD = 2.44), indicating a substantial initial homogeneity between the two groups. The effect size was very small (Cohen's d = 0.122), confirming that the baseline difference was negligible and that the two groups started from a substantially equivalent level.

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Table 5. Comparison of third-grade primary post-test—CG/EG.

Third-Grade	CG			EG			Cohen's d	*p* Value
POST	Avg. 21.64	Standard Deviation 2.82	Standard Error 0.316	Avg 26.22	Standard Deviation 2.61	Standard Error 0.29	1.680	<0.001

The pre–post comparison within the control group of the fourth-grade primary, shown in Table 6 (Pre–post fourth-grade primary—CG comparison), showed a statistically significant increase in mean scores, from M = 13.14 (SD = 2.44) at the pre-test to M = 14.39 (SD = 3.47) at the post-test ($p = 0.003$), indicating an improvement over time in the control group. However, the effect size was small (Cohen's d = 0.281), suggesting that, although statistically significant, the improvement in the control group was limited in magnitude.

Table 6. Pre-test comparison of fourth-grade primary—CG/EG.

Fourth-Grade	CG			EG			Cohen's d	*p* Value
PRE	Avg 13.14	Standard Deviation 2.44	Standard Error 0.227	Avg 13.44	Standard Deviation 2.44	Standard Error 0.219	0.122	0.347

On the contrary, the pre-post comparison within the experimental group of the fourth-grade primary, shown in Table 7 (Pre–post fourth-grade primary comparison—EG), showed a statistically significant increase in mean scores, from M = 13.44 (SD = 2.44) at the pre-test to M = 18.51 (SD = 1.15) at the post-test ($p < 0.001$), suggesting a marked improvement after the intervention. The effect size was large (Cohen's d = 1.996), indicating a substantial and educationally relevant improvement associated with participation in the experimental intervention.

Table 7. Pre–post fourth-grade primary—CG comparison.

Fourth-Grade	PRE			POST			Cohen's d	*p* Value
CG	Avg 13.14	Standard Deviation 2.44	Standard Error 0.227	Avg 14.39	Standard Deviation 3.47	Standard Error 0.323	0.281	0.003

However, the post-test comparison between the experimental group and the control group in the fourth-grade primary, shown in Table 8 (Post-test comparison fourth-grade primary—CG/EG), revealed a statistically significant difference ($p < 0.001$), with the experimental group (M = 18.51, SD = 1.15) achieving superior results to the control group (M = 14.39, SD = 3.47). This difference was accompanied by a very large effect size (Cohen's d = 1.613), confirming that the advantage of the experimental group was not only statistically significant but also substantial in practical and educational terms.

Table 8. Pre–post fourth-grade primary—EG comparison.

Fourth-Grade	PRE			POST			Cohen's d	*p* Value
EG	Avg 13.44	Standard Deviation 2.44	Standard Error 0.219	Avg 18.51	Standard Deviation 1.15	Standard Error 0.104	1.996	<0.001

Overall, the results indicate that the intervention produced statistically significant effects within the experimental group. In the fourth-grade primary, contrary to what was previously reported, the post-test comparison shows a statistically significant advantage for the experimental group, suggesting that the intervention had a clear impact also at this school level (See Table 9). Taken together, the effect-size values strengthen the interpretation of the findings, showing that the intervention was associated with large to very large effects in the experimental groups, whereas the changes observed in the control groups were small or negligible. This pattern supports the educational relevance of the intervention beyond mere statistical significance.

Table 9. Fourth-grade primary post-test comparison—CG/EG.

Fourth-Grade	CG			EG			Cohen's d	*p* Value
POST	Avg 14.39	Standard Deviation 3.47	Standard Error 0.323	Avg 18.51	Standard Deviation 1.15	Standard Error 0.104	1.613	<0.001

5. Discussion

The present study investigated the effects of the SL methodology on the scientific learning outcomes of Italian primary school students through a quasi-experimental pre-test/post-test design involving third and fourth grades. The intervention was carried out over seven months and was supported by teacher training and collaboration with university researchers. It followed a structured protocol consisting of three didactic inputs interspersed with two motor-based pauses, in line with Merrill's *First Principles of Instruction* (Merrill, 2002).

Overall, the results suggest that the effects of SL were not uniform across different school levels, highlighting the importance of considering evolutionary and contextual factors in interpreting the role of this methodology in authentic school contexts. Although the intervention was associated with changes in student performance, the patterns that emerged differed between the third- and fourth-grade primaries, suggesting that the impact of SL may vary depending on the characteristics of the learners and the educational context in which it is implemented.

A first important consideration concerns the positive changes observed over time in the experimental groups. In both the third and fourth grades, students in the experimental condition showed improvement between the beginning and end of the intervention. This trend suggests that the use of Spaced Learning may have supported the consolidation of scientific learning over time. This result is consistent with the theoretical methodological rationale, according to which repeated exposure to key contents, distributed at instructive moments and separated by intervals of cognitive disengagement, can facilitate retention and strengthen learning (Cepeda et al., 2006; Dunlosky et al., 2013; Kelley & Whatson, 2013; Smolen et al., 2016).

At the same time, improvements were also observed in the control groups. These data indicate that student learning can progress even in the absence of experimental methodology, as a result of ordinary teaching, curricular activities, and the natural development of the school experience over time. For this reason, the contribution of the SL should be interpreted within the broader educational context in which the intervention took place. In real classrooms, learning outcomes are rarely attributable to a single factor; rather, they emerge from the interaction between teaching practices, student characteristics, class dynamics, and continuity of education.

The comparison between school levels offers a further interpretative perspective. The differences observed between third- and fourth-grade primary schools could reflect developmental variations in students' cognitive and academic readiness. Older pupils might benefit differently from a structured and repetitive approach such as SL (Dunlosky et al., 2013), as they are better able to retain and rearrange information through subsequent inputs, as well as to engage in tasks that require reflection and reasoning. Conversely, in younger students, the effects of the intervention might emerge in less direct or less immediately measurable forms, such as through increased involvement, attention, or familiarity with scientific language and procedures.

A further relevant element concerns the initial conditions of the groups. In research conducted in school settings, pre-existing differences between classes can influence how the effects of an intervention become visible over time. This is especially important when working in natural educational environments, in which groups are not artificially constructed but reflect the ordinary composition of classes. As a result, interpreting the results requires caution, especially when the characteristics of the groups are not fully comparable at first. Under such conditions, the observed changes should be understood as part of a complex educational process rather than as the effect of a single isolated variable.

A further point of discussion concerns the methods of implementation of the intervention. One of the strengths of this study lies in its ecological validity, as SL was applied in real classrooms by curricular and non-curricular teachers under highly controlled experimental conditions. This aspect increases the practical relevance of the results, as it shows that the methodology can be integrated into daily science teaching in primary school (Kelley & Whatson, 2013). At the same time, however, implementation in authentic contexts inevitably introduces a degree of variability. Although the protocol was clearly defined, teachers maintained some flexibility in adapting activities to specific curricular content and the needs of the classes. This flexibility is pedagogically significant, but it may also have influenced the coherence of the intervention in different contexts.

From this perspective, the quality and consistency of the implementation become key interpretive elements. The variability observed in the outcomes could depend not only on the characteristics of the SL itself, but also on the way in which the methodology was concretely implemented in the different classes. Differences in pacing, classroom management, use of teaching materials, and adherence to the sequence of inputs and intervals may have shaped students' learning experiences. For this reason, future research should devote more attention to documenting how the methodology is translated into practice and how this variation can be linked to the observed outcomes.

The results of this research also raise important questions regarding the nature of the learning outcomes considered. The present study focused on two main dimensions: scientific knowledge and some aspects of scientific reasoning and understanding of the Nature of Science. These dimensions are both central to school education and teaching but may not respond in the same way to innovation. The acquisition of content knowledge can be supported more directly by structured repetition and reinforcement, while the development of scientific reasoning and epistemological understanding may require longer time, more explicit reflection, and richer opportunities for discussion and inquiry. It is therefore possible that the effects of SL differ depending on the specific learning domain considered.

More generally, the results support a cautious but significant interpretation of SL as a promising teaching strategy in primary-grade science learning (Dunlosky et al., 2013; Kelley & Whatson, 2013). The methodology appears compatible with school practice and potentially useful for supporting learning over time. However, the results of the present study also suggest that its educational value should not be considered automatic or uniform. Rather, its effectiveness appears to depend on a combination of factors, including the age of the students, the characteristics of the class, the way the methodology is implemented, and the type of outcomes assessed.

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Additionally, the statistically significant improvement observed in the fourth-grade control group deserves specific consideration. Although this increase may partly reflect normal curricular progression, maturation processes, greater familiarity with the test format, or other contextual factors not directly controlled within the study design, its magnitude was small, as indicated by Cohen's d = 0.281. This finding, therefore, suggests that some learning gains occurred independently of the experimental intervention. However, the improvement observed in the fourth-grade experimental group was considerably larger, with Cohen's d = 1.996 in the pre–post comparison, and the post-test comparison between the experimental and control groups also showed a very large effect size, Cohen's d = 1.613. These results suggest that, while general developmental and curricular factors may have contributed to students' progress, the SL intervention appears to have produced an additional and educationally meaningful effect. Nevertheless, this finding should be interpreted with caution, as the improvement in the control group represents a potential threat to internal validity.

Taken together, these considerations suggest that Spaced Learning may represent a valid approach to enhance science teaching in primary school, especially when it is embedded within a coherent and well-supported teaching practice. At the same time, the variability of the results indicates the need for further research capable of clarifying the educational conditions in which this methodology can lead to more stable and consistent benefits for students.

6. Conclusions

This study explored the effects of a seven-month SL intervention on the science learning outcomes of third and fourth-grade primary students in Italian schools. The results suggest that the methodology can support scientific learning, although its impact seems to vary in relation to school level and classroom context. Overall, SL emerges as a viable and promising approach to education and teaching in primary school. However, its benefits must be interpreted in relation to the broader educational environment and the specific conditions of implementation. More research is needed to better understand how and under what circumstances this methodology can more effectively promote students' scientific knowledge and scientific reasoning.

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