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Article

The Effect of Nanolearning on Scientific Classification Skills among Third-Grade Students in Science Education

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Abstract: This study aimed to investigate the effect of the nanolearning strategy on developing the scientific classification skill among third-grade students in science. To achieve this objective, the researcher developed a scientific classification skill test measuring three main dimensions: identifying common and different characteristics, grouping elements according to a specified characteristic, and identifying the classification criterion. The study participants consisted of 40 third-grade students at Al-Qimma International School, affiliated with the Directorate of Education for Qasaba Irbid, during the second semester of the 2025/2026 academic year. The participants were divided into two groups: an experimental group consisting of 20 students who were taught using the nanolearning strategy and a control group consisting of 20 students who were taught using the conventional method. The study employed a quasi-experimental design, and the scientific classification skill test was administered to both groups before and after the intervention. The results revealed statistically significant differences in the scientific classification skill as a whole and in its three dimensions—identifying the classification criterion, grouping elements according to a specified characteristic, and identifying common and different characteristics—between the two study groups, in favor of the experimental group. The results also indicated that the nanolearning strategy had a large effect on developing the scientific classification skill among third-grade students in science.

Keywords: Nanolearning Strategy, Scientific Classification Skill, Science, Third-Grade Students

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1. Introduction

Science education at the elementary level plays an important role in helping students understand the natural world and develop the skills needed to investigate it. Learning science involves more than acquiring facts and concepts; it also requires students to observe objects and phenomena, compare their characteristics, identify patterns, and draw conclusions from the evidence available to them. These skills are particularly important during the early school years, when children are developing their understanding of the world through direct experiences with plants, animals, materials, and other elements of their surroundings. The science curriculum in Jordan emphasizes the development of scientific inquiry and thinking skills as part of students' learning experiences [1]. Similarly, the Framework for K–12 Science Education highlights the importance of engaging students in scientific practices, including analyzing information, identifying patterns, and developing explanations based on evidence [2]. These perspectives support the need to provide elementary students with opportunities to learn science through observation, exploration, and practical activities rather than relying mainly on memorization.

Scientific process skills are an essential part of this learning experience because they enable students to examine information systematically and make sense of the similarities and differences they observe. One of these skills is scientific classification, which involves identifying shared or distinct characteristics and grouping objects or organisms according to a selected criterion. Classification is particularly relevant to elementary science because students frequently work with pictures, natural objects, living organisms, and materials that can be organized according to observable features. When students classify objects, they must do more than recognize them individually; they need to examine their characteristics, compare them with those of other objects, and decide which features are relevant to the task. Kim and Shin investigated the development of observation and classification process skills among elementary school students through an instructional program based on scientific thinking strategies [3]. Their work reflects the importance of providing students with structured opportunities to practice these skills. Research on inquiry-based science learning has also examined ways of helping younger learners develop basic science process skills through practical learning activities [4]. Together, these studies support the value of addressing scientific skills directly as part of elementary science instruction.

The development of classification skills requires appropriate learning experiences in which students can observe examples, recognize relevant characteristics, and apply a consistent rule when organizing information. This process can be challenging for young learners if they are expected to classify objects without sufficient explanation or practice. Students may identify an object's most noticeable feature without understanding whether that feature is relevant to the classification criterion. For this reason, instruction should provide clear examples and opportunities to practice the skill in manageable steps. Van Uum et al. discussed the importance of inquiry-based science education and the role of teachers in supporting primary school students as they engage in scientific activities [5]. More broadly, Furtak et al.'s meta-analysis of experimental and quasi-experimental studies found that inquiry-based science teaching can support student learning, although outcomes depend partly on the instructional approaches used and the balance between teacher guidance and student involvement [6]. Lazonder and Harmsen similarly found that guidance can support learning activities, performance, and learning outcomes in inquiry-based learning environments [7]. These findings suggest that elementary students benefit from opportunities to investigate and practice scientific skills within a learning environment that provides appropriate direction and feedback.

The way instructional content is presented is another important consideration when planning science lessons for young learners. When students encounter too much information at once, they may find it difficult to identify the main idea or focus on the skill they are expected to develop. Sweller's research on cognitive load explains how the demands imposed by a learning task can affect the cognitive resources available for learning [8]. Mayer's work on multimedia learning also examines how the organization and presentation of words and visual materials can influence the way learners process information [9]. These perspectives are relevant to elementary science education, where teachers often use illustrations, diagrams, photographs, and practical examples to explain scientific concepts. They provide a rationale for considering instructional approaches that organize content clearly and direct students' attention toward specific learning objectives. However, the effectiveness of such approaches depends on the quality of the instructional design, not simply on the amount of information presented in each lesson.

One approach that has received attention in educational research is nanolearning, which involves presenting learning content in small, focused units designed to address a particular idea or learning objective. Related research on microlearning has examined the use of short learning activities and their integration into different educational settings. Denojean-Mairet et al. reviewed the literature on microlearning and its integration with social media, identifying trends and challenges in the use of short learning units [10].

Buchem and Hamelmann also discussed microlearning as an approach that can support ongoing learning through relatively small and focused learning activities [11]. More recently, Monib et al. reviewed research on microlearning and proposed a framework that connects the design of short learning units with specific objectives, instructional methods, and intended learning outcomes [12]. This literature suggests that the organization of learning content into smaller units is worth examining as an instructional design option. Nevertheless, microlearning and nanolearning are not necessarily interchangeable terms, and evidence concerning one approach should not automatically be treated as evidence for the other. In the present study, nanolearning refers to the planned presentation of science content through short, focused instructional units, each designed to address a particular aspect of the lesson or a specific learning task.

The use of nanolearning may be particularly relevant to scientific classification because this skill can be practiced through a sequence of clearly defined activities. For example, students learning about the plant life cycle may first examine the characteristics of different plant-related images or objects, then compare their features, identify similarities and differences, and finally group the examples according to an appropriate criterion. Each activity can focus on one aspect of the classification process before students apply the skill to a more complete task. This arrangement may help students understand what they are expected to do and give them repeated opportunities to practice the targeted skill. The rationale is consistent with research emphasizing the importance of clear learning objectives, manageable instructional units, and appropriate learning activities in the design of microlearning [10]–[12]. However, the effectiveness of nanolearning for scientific classification among elementary school students remains an empirical question that requires investigation in the specific classroom context.

Recent research has begun to examine nanolearning in relation to particular educational outcomes. Radzitskaya and Islamov investigated the use of nanolearning in developing professional competencies among students, with attention to self-regulation [13]. Their work provides a relevant example of research examining nanolearning beyond the simple delivery of information, although its educational context differs from elementary science education. Alwazzan examined adaptive content based on nanolearning and its relationship to working memory quality among high school students using a quasi-experimental design [14]. The reported findings indicated improvement in working memory scores following the intervention among students in the experimental group [14]. This study provides a recent example of research into the potential application of nanolearning to a specific learning-related outcome. Nevertheless, working memory and self-regulation differ from scientific classification, and studies involving older students cannot establish whether the same instructional approach will be effective for younger learners. Further research is therefore needed to examine nanolearning in relation to particular scientific process skills at the elementary level.

The broader literature on microlearning also points to the importance of examining how short learning activities are designed and implemented. Denojean-Mairet et al. identified different ways in which microlearning has been incorporated into educational practices and discussed challenges associated with its use [10]. Monib et al. likewise emphasized the importance of connecting short instructional units with appropriate objectives, learning activities, and assessment rather than assuming that dividing content into smaller sections will automatically improve learning [12]. Research on mobile-based microlearning has also examined how this approach has been used to support learning in adult education contexts [15]. Although such studies provide useful information about instructional design and the potential uses of short learning units, their findings must be interpreted in relation to the populations and outcomes investigated. The extent to which these approaches can support the development of observable scientific skills among third-grade students remains insufficiently established by the literature discussed here.

Inquiry-based science education provides a further basis for examining the relationship between instructional design and scientific process skills. When students investigate natural phenomena, they need opportunities to observe, compare, interpret information, and explain the decisions they make. These activities can be incorporated into lessons on the plant life cycle by asking students to examine relevant examples, identify their characteristics, and classify them according to specified criteria. Research on inquiry-based science teaching indicates that student learning can benefit from appropriate guidance and well-designed learning activities [6], [7]. In this context, nanolearning may offer a way to organize instruction so that students work through the targeted skill in short, connected stages. The teacher can introduce each stage, provide examples, observe students' responses, and offer feedback before students proceed to the next task. This is a proposed instructional rationale rather than an established finding about nanolearning's effectiveness in scientific classification.

Although the available literature addresses science process skills, inquiry-based learning, cognitive load, multimedia learning, and microlearning, these areas do not answer exactly the same research question. Studies of scientific process skills have examined the development of observation and classification [3], [4], while research on inquiry-based learning has focused on student engagement in scientific activities and the support needed to learn through inquiry [5]–[7]. Research on microlearning and nanolearning has examined the organization of learning content and its potential relationship to different educational outcomes [10]–[15]. However, the findings from these areas do not, by themselves, demonstrate that nanolearning improves scientific classification skills among third-grade students. This distinction identifies a need for research that examines the approach in a specific elementary science setting and measures students' performance on a clearly defined scientific skill.

Accordingly, the present study investigates the effect of nanolearning on scientific classification skills among third-grade students in science education, using the plant life cycle as the instructional context. The approach involves presenting the lesson through short, focused learning units and providing activities that allow students to practice observing characteristics, comparing examples, identifying similarities and differences, and classifying items according to appropriate criteria. The study seeks to determine whether this way of organizing instruction can improve students' performance in scientific classification. By focusing on a specific scientific process skill among young learners, the study aims to contribute evidence concerning the use of nanolearning in elementary science education and to clarify its potential value beyond the learning outcomes examined in previous studies.

2. Materials and Methods

The present study followed an experimental approach using a quasi-experimental design, involving two groups of third-grade elementary students: an experimental group taught using the nano-teaching strategy and a control group taught using the conventional method. A scientific classification skills test was administered to participants in both study groups before and after the intervention, with the aim of determining the effect of the nano-teaching strategy on the development of students' scientific classification skills.

2.1 Study Participants

The study participants consisted of third-grade elementary students at Al-Qumma International School, affiliated with the Irbid Kasbah Directorate of Education, during the second semester of the 2025–2026 school year. The school was selected through convenience sampling due to the availability of the facilities and resources necessary to implement the study procedures.

Two classes of third-grade elementary students were selected and divided into two groups: an experimental group taught using the nano-teaching strategy and a control group taught using the conventional method. A pilot group of third-grade elementary students from outside the main study sample was also selected to verify the psychometric properties of the study instrument in terms of validity and reliability.

2.2 Research Instrument: Scientific Classification Skills Test

To achieve the objectives of the present study, the researcher developed a test to measure scientific classification skills among third-grade elementary students in science. The test consists of items that measure three main dimensions of scientific classification skills, namely: identifying common and differing characteristics; grouping items according to a specific characteristic; and determining the classification criterion. The researcher developed the test according to a set of organized procedural steps aimed at ensuring its suitability for the study's objectives and the content of the "Plant Life Cycle" lesson, as well as verifying its validity and reliability, as follows:

Development of the Scientific Classification Skills Test

The scientific classification skills test was developed according to a set of organized methodological steps, as follows:

2.3 Defining the Purpose of the Test

The researcher began by defining the main objective of the test, which was to measure the performance level of third-grade elementary students in the skill of scientific classification, as defined in the study, in accordance with the educational objectives of the science curriculum and the content of the lesson on "The Life Cycle of Plants."

Defining the Scientific Classification Skill and Its Dimensions

In defining the scientific classification skill and its dimensions, the researcher relied on educational literature specializing in scientific process skills, as well as the frameworks and standards for science education at the elementary level, particularly those related to the learner's ability to observe characteristics, compare objects or phenomena, and grouping them into categories based on common characteristics or criteria. The researcher also drew upon the general and specific frameworks for science, along with its standards and performance indicators, issued by the National Center for Curriculum Development, which emphasizes the importance of developing learners' scientific thinking skills and practices at various stages of education, including dealing with the characteristics of objects and classifying and organizing them. Science education standards indicate that students in the early grades learn by observing the characteristics of objects, comparing them, classifying them, and grouping them according to common characteristics (National Research Council, 1996, p. 126).

Accordingly, the researcher adopted the skill of scientific classification as one of the scientific process skills appropriate for third-grade elementary students and operationally defined its dimensions in the present study as three main dimensions, namely:

Identifying common and differing characteristics: the student's ability to observe elements or stages of a plant's life cycle and identify similarities and differences among them based on observable and specific characteristics.

Grouping elements based on a specific characteristic: The student's ability to organize elements or images into groups based on a specific shared characteristic or trait, which aligns with the approach of science education standards in early grades toward using the characteristics of objects to separate, sort, and group them.

Identifying the classification criterion: The student's ability to identify the characteristic or criterion used to group a set of items or classify them into specific categories.

The researcher adopted these three dimensions as procedural indicators of the scientific classification skill in the present study, in accordance with the nature of the plant life cycle lesson content and the developmental level of third-grade elementary students.

A set of performance indicators was formulated for each dimension to reflect the student's ability to apply the classification skill in scientific situations related to the "Plant Life Cycle" lesson content. Table (1) presents the main dimensions of scientific classification skills and their corresponding performance indicators.

Table 1. Dimensions of the Scientific Classification Skill and Their Corresponding Performance Indicators

Dimension / Skill	Performance Indicators
Identifying Common and Distinctive Characteristics	The student identifies the common characteristics among elements or stages of a plant's life cycle.
	The student identifies the differences between elements or stages of a plant's life cycle.
Grouping Elements by a Specific Characteristic	The student groups elements or images that share a specific characteristic.
	The student classifies elements into groups based on a specific characteristic or trait.
Identifying the Classification Criterion	The student identifies the characteristic on which the classification of a set of elements is based.
	The student selects the appropriate criterion for classifying a set of items.

2.4 Analysis of Lesson Content

The researcher analyzed the content of the "Plant Life Cycle" lesson designed for third-grade students, with the aim of identifying the concepts, information, and attitudes that can be used to assess scientific classification skills, and linking the test items to the content studied by the students, thereby ensuring that the test accurately reflects the targeted educational content.

2.5 Preparation of the Specifications Table

The researcher prepared a test specification table linking the content of the "Plant Life Cycle" lesson to the dimensions of the scientific classification skill, the number of test items, and the relative weights of each dimension, in order to ensure a balanced distribution of items and achieve content validity.

2.6 Formulation of Test Items

The test items were formulated in light of the dimensions and performance indicators specified for the scientific classification skill, and in a manner appropriate to the age and cognitive characteristics of third-grade elementary students. The items focused on situations, images, and elements related to the stages of the plant life cycle, so as to measure the student's ability to identify common and differing characteristics, group elements according to a specific characteristic, and determine the classification criterion.

The following considerations were taken into account when drafting the items:

Clarity and ease of understanding.

Appropriateness of the paragraphs for the students' age group.

Relevance of the paragraphs to the content of the "Plant Life Cycle" lesson.

Each paragraph measures the dimension specified for it.

Avoiding ambiguity and overlap between paragraphs.

Variety of situations and images used in the assessment.

2.7 Preparing Test Instructions

The researcher prepared clear and straightforward test instructions, which included an explanation of how to answer the items, a description of what is required of the student in each item, and an emphasis on reading the question or observing the images carefully before answering. This was done to standardize the administration procedures and ensure students' understanding of the test requirements.

2.8 Preliminary Version of the Test

After finalizing the dimensions and performance indicators, analyzing the lesson content, preparing the specifications table, and drafting the items and instructions, the researcher prepared a preliminary version of the test to be presented to a group of expert reviewers to verify the suitability of the items for the dimensions of the scientific classification skill, the clarity of their wording, their suitability for third-grade students, and their relevance to the lesson content on "The Life Cycle of Plants," in preparation for making the necessary adjustments and finalizing the test.

2.9 Validity of the Scientific Classification Skills Test

To verify the validity of the scientific classification skills test, the researcher presented the preliminary version of the test—accompanied by a list of the dimensions of scientific classification skills and their corresponding behavioral indicators—to a group of expert reviewers specializing in science curricula and teaching methods, as well as measurement and assessment, at Jordanian universities, as well as a number of science teachers. The purpose was to solicit their opinions on the clarity of the test instructions, the appropriateness of the items for the age and cognitive level of third-grade elementary students, the extent to which the items align with the content of the plant life cycle lesson, the relevance of each item to the dimension it was designed to measure, the extent to which the items covered the main dimensions of scientific classification skills, the accuracy of their linguistic formulation, and the clarity of the answer choices and correct answers.

In light of the reviewers' opinions and observations, the researcher made the necessary modifications to the test, which included revising some items and rephrasing others more clearly, deleting items that did not demonstrate sufficient correlation with the targeted dimension, and adding or modifying certain items to ensure representation of the specified dimensions of scientific classification skills, while verifying that the items were appropriate for the content of the plant life cycle lesson and the characteristics of third-grade students. Thus, the test was finalized after incorporating the reviewers' comments, thereby ensuring content validity and the suitability of its items for measuring the scientific classification skill targeted in the study.

2.10 Reliability of the Scientific Classification Skill Test

To verify the reliability of the scientific classification skills test, the test was administered to members of the pilot sample, then re-administered to the same sample members two weeks after the first administration. The researcher calculated the test-retest reliability coefficient using Pearson's correlation coefficient between the sample participants' scores on the two administrations. She also calculated the internal consistency reliability coefficient using Cronbach's alpha for each dimension of the scientific classification skill test and for the test as a whole. Table (2) shows the resulting reliability coefficients.

Table 2. Test-Retest and Internal Consistency Reliability Coefficients for the Dimensions of the Scientific Classification Skill Test and for the Test as a Whole

Dimensions of the Scientific Classification Skill Test	Test-Retest Reliability Coefficient	Internal Consistency Coefficient
Identifying Common and Distinctive Characteristics	0.88	0.9
Grouping Items by a Specific Characteristic	0.86	0.88
Defining the classification criterion	0.84	0.86
Combined test items	0.89	0.92

Table (2) shows that the test-retest reliability coefficient for the test as a whole was (0.89), while the test-retest reliability coefficients for the dimensions of scientific classification skills ranged from (0.84–0.88). The internal consistency coefficient for the test as a whole was 0.92, while the internal consistency coefficients for the dimensions ranged from 0.86 to 0.90. These values indicate that the test possesses an adequate degree of reliability, which supports the reliability of its results in measuring scientific classification skills among third-grade elementary students in the present study.

2.11 Test Administration

The scientific classification skills test was administered as a pre-test and post-test to the study participants after explaining the necessary instructions to the students and instructing them to read the test instructions and items carefully and to answer all items according to the instructions provided with the test. The pre-test was administered before beginning instruction on the plant life cycle using the nano-teaching strategy for the experimental group, and the conventional method for the control group. The posttest was administered after completing the instruction on the study's specified content, with the aim of determining the effect of the nano-teaching strategy on the development of scientific classification skills among third-grade elementary students.

2.12 Test Grading

The scientific classification skills test was graded according to a pre-prepared answer key. The researcher awarded one point for each correct answer and zero points for each incorrect or blank answer. Thus, the total score for the test ranged from 0 to 20 points, with a higher score indicating a higher level of student performance in scientific classification skills.

2.13 Equivalence of the Two Study Groups on the Pre-test

To verify the equivalence of the two study groups (control and experimental) before implementing the experimental treatment, the arithmetic means and standard deviations of the two groups' performance on the pre-test for scientific classification skills were calculated. A t-test for two independent samples was also used to determine the significance of the differences between the arithmetic means, as shown in the following table.

Table 3. Equivalence of the two study groups on the pre-test

Group	Number	Arithmetic Mean	Standard Deviation	t-value	Degrees of freedom	Significance
Control	20	2.3667	0.37307	-0.128	38	0.899
Experimental	20	2.3833	0.4495			

The results presented in Table (3) show that the arithmetic mean for the control group on the pre-test was (2.3667) with a standard deviation of (0.37307), while the arithmetic mean for the experimental group was (2.3833) with a standard deviation of (0.44950). The t-test value ( ) was 0.128 at 38 degrees of freedom, and the significance value was 0.899, which is greater than the accepted significance level ($\alpha \leq 0.05$).

Therefore, there are no statistically significant differences between the mean performance scores of the control and experimental groups on the pre-test for scientific classification skills, indicating that the two groups were equivalent in the skill under study prior to the experiment, and allowing for a comparison between them after the experimental treatment was applied.

3. Results

classification skill, were calculated according to the teaching strategy (conventional vs., nano-education), as shown in Table (4).

Table 4. Arithmetic Means and Standard Deviations of Pre- and Post-Test Performance and Adjusted Arithmetic Means of Post-Test Performance in Scientific Classification Skills Combined, According to Teaching Strategy

Teaching Strategy Pre-test Performance Post-test Performance Adjusted Post-Test Performance

Teaching Strategy	Pre-test Performance		Post-test Performance		Adjusted Post-Test Performance	
	Arithmetic Mean	Standard Deviation	Arithmetic Mean	Standard Deviation	Adjusted arithmetic mean	Standard error
Standard Deviation	2.3667	0.37307	2.9667	0.38843	2.967	0.158
Nanoeducation	2.3833	0.4495	4.5667	0.90547	4.566	0.158

Table (4) shows an apparent difference between the pre- and post-test arithmetic means of the experimental group, who were taught using the nano-teaching strategy. It also shows an apparent difference between the post-test arithmetic means of the two study groups: the control and experimental groups. To determine the statistical significance of the apparent differences in post-test performance according to the teaching strategy, and after controlling for the effect of pre-test differences in the scientific classification skills of the two study groups, an analysis of covariance (ANCOVA) was used, as shown in Table (5).

Table 5. Results of the one-way analysis of covariance (ANCOVA) for the post-test performance of study participants on the scientific classification skill, combined according to teaching strategy

Source of Variation Sum of Squares Degrees of Freedom Mean Squares F-value Statistical Significance Effect size

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	Statistical Significance	Effect size
A priori (concomitant) test	0.05	1	0.05	0.1	0.754	0.003
Teaching Strategy	25.542	1	25.542	51.377	0	0.581

Error	18.395	37	0.497	—	—	—
Adjusted Total	44.044	39	—	—	—	—

Considering the results of the analysis of variance shown in Table (5), it can be observed that the p-value for the teaching strategy was (0.000), which is less than the accepted significance level ($\alpha = 0.05$). This indicates the presence of a statistically significant difference between the mean performance scores of the participants in the two study groups on the post-test for the scientific classification skill as a whole, attributable to the teaching strategy.

Consequently, the main null hypothesis—which states that there is no statistically significant difference between the mean performance scores of the study participants in the scientific classification skill as a whole attributable to the teaching strategy—is rejected at the significance level ($\alpha \leq 0.05$).

As shown by the adjusted mean scores presented in Table (5), the statistically significant difference favored the experimental group participants who were taught using the nano-teaching strategy; the adjusted mean score for the experimental group was (4.566), while that for the control group was (2.967).

Furthermore, the partial eta-squared value for the teaching strategy was 0.581, indicating that the teaching strategy contributed to explaining 58.1% of the variance in post-test performance on the scientific classification skill among the study participants, after controlling for the effect of pre-test performance.

This result can be explained by the fact that the nano-teaching strategy enabled students to engage with the scientific classification skill through concise and focused instructional content, introducing the skill gradually. This helped them focus on the characteristics associated with the classification process and then move on to applying it in various learning situations. Furthermore, breaking down the content and activities into specific steps helped reduce the cognitive load and provided repeated opportunities for practice and feedback. This finding aligns with what Radzitskaya and Islamov (2024) noted regarding the nature of micro-learning, which is based on presenting information in small, specific chunks, and is consistent with what Kim and Shin (2015) emphasized regarding the importance of employing hands-on learning activities to develop classification skills among elementary school students. It also aligns with the guidelines of the National Center for Curriculum Development (2019), which emphasize the development of scientific process skills in learners through practice and understanding, rather than merely acquiring information.

This result may also be attributed to the fact that the nature of scientific classification skills requires a sequential process that begins with observing and comparing characteristics, followed by selecting an appropriate criterion and organizing the elements into groups; these steps can be easily broken down into short, step-by-step instructional activities, which aligns with the characteristics of the nano-teaching strategy. Thus, the result suggests that employing this strategy in science instruction can support the development of observable and measurable scientific skills among elementary school students.

Second Research Question: Is there a statistically significant difference at the significance level ($\alpha \leq 0.05$) between the arithmetic means of the study participants' performance on each dimension of scientific classification skills attributable to the teaching strategy (conventional vs., nano-teaching)?

The following sub-null hypotheses were derived from the second research question:

First Sub-Null Hypothesis:

There is no statistically significant difference at the significance level ($\alpha \leq 0.05$) between the arithmetic means of the study participants' performance in identifying common and different characteristics—as one dimension of scientific classification skills—attributable to the teaching strategy (conventional vs., nano-education).

Second null hypothesis:

There is no statistically significant difference at the significance level ($\alpha \leq 0.05$) between the arithmetic means of the study participants' performance in grouping items according to a specific characteristic—as one of the dimensions of scientific classification skills—attributable to the teaching strategy (conventional vs., nano-education).

Third Sub-Null Hypothesis:

There is no statistically significant difference at the significance level ($\alpha \leq 0.05$) between the arithmetic means of the study participants' performance in determining classification criteria as one of the dimensions of scientific classification skills, attributable to the teaching strategy (conventional vs., nano-education).

To answer the study's second question and test its null hypotheses, the arithmetic means and standard deviations of the study participants' performance on the pre- and post-tests were calculated for each dimension of scientific classification skills, according to the teaching strategy. The adjusted arithmetic means and standard deviations for post-test performance were also calculated, and Table (6) presents these results.

Table 6. Arithmetic Means and Standard Deviations of the Study Participants' Pre-test, Post-test, and Adjusted Post-test Performance on the Dimensions of Scientific Classification Skills, According to the Teaching Strategy

Skill Teaching Strategy Pre-test Performance: Arithmetic Mean Pre-test performance: Standard deviation Post-test performance: arithmetic mean Post-test performance: Standard deviation Adjusted Post-Test Performance: Adjusted Arithmetic Mean Standard Error

Skill	Teaching Strategy	Pre-test Performance: Arithmetic Mean	Pre-test performance: Standard deviation	Post-test performance: arithmetic mean	Post-test performance: Standard deviation	Adjusted Post-Test Performance: Adjusted Arithmetic Mean	Standard Error
Determining the Classification Threshold	Normality	2.45	0.826	3.2	0.696	3.216	0.262
	Nanoeducation	2.5	0.827	4.95	1.468	4.934	0.262
Grouping elements by a specific property	Normality	2.35	0.489	2.9	0.852	2.899	0.229
	Nanoeducation	2.4	0.503	4.9	1.165	4.901	0.229
Identifying Common and Different Characteristics	Normality	2.3	0.865	2.8	0.768	2.79	0.284
	Nanoeducation	2.25	0.786	3.85	1.599	3.86	0.284

Table (6) shows apparent differences between the pre- and post-test arithmetic means of the experimental group, which was taught using the nano-teaching strategy, as

well as apparent differences between the post-test arithmetic means of the control and experimental groups in the dimensions of scientific classification skills. To determine the statistical significance of the apparent post-test differences according to the teaching strategy, after controlling for differences in the pre-test arithmetic means of the two study groups' performance on the dimensions of scientific classification skills, a multivariate analysis of covariance (MANCOVA) was used, as shown in Table (7).

Table 7. Results of the multivariate analysis of covariance (MANCOVA) for the post-test mean scores of study participants on the dimensions of scientific classification skills according to teaching strategy

Source of Variation	Skill	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	Statistical Significance	Effect size
Associate (Determining the a priori classification criterion)	Determination of Classification Criteria	0.658	1	0.658	0.482	0.492	0.014
	Group elements by a specific property	2.125	1	2.125	2.027	0.163	0.055
	Identifying Common and Different Characteristics	0.944	1	0.944	0.587	0.449	0.016
Associated (grouping elements according to a predefined attribute)	Determination of Classification Criteria	2.036	1	2.036	1.492	0.23	0.041
	Group elements by a specific property	0.315	1	0.315	0.3	0.587	0.009
	Identifying Common and Different Characteristics	1.73	1	1.73	1.075	0.307	0.03
Accompanying (Common and Distinctive Characteristics)	Determination of Classification Criteria	0.001	1	0.001	0.001	0.979	0
	Group elements based on a specified `` property	0.121	1	0.121	0.115	0.736	0.003
	Identifying Common and Different Characteristics	0.45	1	0.45	0.28	0.6	0.008
Teaching Strategy	Determination of Classification Criteria	29.312	1	29.312	21.472	0.000*	0.38
	Group elements by a specific property	39.82	1	39.82	37.981	0.000*	0.52
	Identifying Common and Different Characteristics	11.364	1	11.364	7.065	0.012*	0.168

Error	Determination of Classification Criteria	47.78	35	1.365	—	—	—
	Group elements by a specific property	36,694	35	1.048	—	—	—
	Identifying Common and Different Characteristics	56,297	35	1,608	—	—	—

* Statistically significant at (α = 0.05).

Based on the results of the analysis of variance presented in Table (7), the following observations can be made:

- The p-value for Hotelling's Trace test based on the teaching strategy variable was 0.000, which is less than ($\alpha \leq 0.05$), indicating the presence of a statistically significant difference in the dimensions of scientific classification skills attributable to the teaching strategy, as the value of Hotelling's Trace was (2.064) and the effect size was (0.674).

- The p-value for the dimension of determining the classification criterion according to teaching strategy was 0.000, which is less than ($\alpha \leq 0.05$), indicating rejection of the third alternative null hypothesis, which states that there is no statistically significant difference between the arithmetic means of the study participants' performance on the dimension of determining classification criteria attributable to the teaching strategy. From the adjusted dimensional mean scores shown in Table (7), it is evident that the statistically significant difference favored the experimental group participants who were taught using the nano-teaching strategy, as the adjusted dimensional mean score for the experimental group was (4.934), compared to (3.216) for the control group ( ). The effect size was calculated at 0.380, which is a large effect size, indicating that 38.0% of the variance in post-test performance on the "determining classification criteria" dimension is attributable to the teaching strategy.

- The p-value for the dimension of grouping items according to a specific characteristic based on the teaching strategy was 0.000, which is less than ($\alpha \leq 0.05$), indicating rejection of the second alternative null hypothesis, which states that there is no statistically significant difference between the arithmetic means of the study participants' performance on the "grouping items by a specific characteristic" dimension attributable to the teaching strategy. From the adjusted dimensional mean scores shown in Table (7), it is evident that the statistically significant difference favored the participants in the experimental group who were taught using the nano-teaching strategy, as the adjusted dimensional mean score for the experimental group was (4.901), compared to (2.899) for the control group. The effect size was calculated at 0.520, which is a large effect size, indicating that 52.0% of the variance in post-test performance on the dimension of grouping elements according to a specific characteristic is attributable to the teaching strategy.

- The p-value for the dimension of identifying common and different characteristics according to the teaching strategy was (0.012), which is less than ($\alpha \leq 0.05$), indicating rejection of the first alternative hypothesis, which states that there is no statistically significant difference between the arithmetic means of the study participants' performance on the dimension of identifying common and different characteristics attributable to the teaching strategy. From the adjusted post-test arithmetic means shown in Table (7), it is evident that the statistically significant difference favored the participants in the experimental group who were taught using the nano-teaching strategy, as the adjusted post-test arithmetic mean for the experimental group was (3.860), compared to (2.790) for the control group. The effect size was calculated at 0.168, which is a large effect

size, indicating that 16.8% of the variance in post-test performance on the dimension of identifying common and different characteristics is attributable to the teaching strategy.

This result can be explained by the fact that the nano-teaching strategy allowed for the presentation of the scientific classification skill in a gradual and segmented manner, broken down into short, specific instructional steps. This helped students focus on the characteristics of the elements, compare them, identify the appropriate classification criterion, and then group the elements according to their shared characteristics. Furthermore, the sequence of short activities and repeated practice provided students with greater opportunities to apply the skill and receive feedback. This finding is consistent with Kim and Shin (2015), who emphasized the importance of hands-on learning activities in developing classification skills among elementary school students, and is also in line with Radzitskaya and Islamov (2024), who noted that presenting content in small, specific chunks can support the organization of the learning process. It also aligns with the guidelines of the National Center for Curriculum Development (2019), which emphasize the importance of developing scientific process skills through practice and application.

This result may also be attributed to the suitability of the nano-teaching strategy for the nature of scientific classification skills, which require a sequential process beginning with observing characteristics, followed by comparison, selection of a classification criterion, and organization of elements into groups; breaking these procedures down into short tasks facilitated their learning and practice among third-grade elementary students.

4. Discussion

The findings indicate that nano-teaching was more effective than conventional teaching in developing third-grade students' scientific classification skills. This may be attributed to presenting content in short, focused, and sequential activities that help students observe characteristics, compare objects, identify classification criteria, and group objects according to shared properties. Repeated practice and feedback may have further supported students' skill development.

These findings are consistent with Radzitskaya and Islamov [13], who examined nanolearning in relation to students' professional competencies and self-regulation, and Kim and Shin [3], who highlighted the importance of practical activities in developing observation and classification skills. The findings are also consistent with the emphasis placed by the National Center for Curriculum Development [1] on developing scientific skills through practice and application. The stronger effects observed in determining classification criteria and grouping objects suggest that nano-teaching may be particularly suitable for teaching scientific skills that involve sequential steps and practical application.

5. Conclusion

The study aimed to investigate the effectiveness of nano-teaching in developing scientific classification skills among third-grade elementary students compared with conventional teaching. The findings demonstrated the effectiveness of nano-teaching in improving overall classification skills and their three dimensions: identifying common and different characteristics, grouping objects, and determining classification criteria. Therefore, nano-teaching is a promising approach for elementary science education, and teachers are encouraged to incorporate short, structured, and practice-based activities into their instruction. Further studies are recommended to examine its effectiveness in developing other scientific skills and across different educational contexts.

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