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The Construction of Precursor Models in the Thinking of Young Children: The Case of Expansion and Contraction of Metals

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Abstract: The aim of the current study is to examine how preschool children overcome their difficulties regarding thermal expansion and contraction and construct in their minds a precursor model; that is, an entity compatible with school knowledge. Having investigated these difficulties through a pretest, a teaching intervention was implemented based on both the telling of a fairy tale and the carrying out of experimental activities. Finally, the changes in children's thinking were studied with a posttest. The study involved 36 children aged 4–6 years who voluntarily participated in individual semistructured interviews conducted by three researchers in a special kindergarten setting. The results of the study revealed statistically significant progress in children's responses between pre- and posttests. Furthermore, the finding of almost 1/3 of children's responses being compatible with school knowledge indicates that (a) it is possible for children of that age to construct a precursor model for thermal expansion and contraction and (b) the combination of storytelling along with experimental activities is probably an appropriate teaching strategy.

Keywords: mental representations; preschool children; physical sciences; thermal expansion and contraction; precursor model

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1. Introduction

The approach to the phenomena of the natural world and the related concepts as they are formulated within the context of science education has been an important field of research in early childhood in recent decades. Indeed, research efforts with different origins, such as Early Childhood Education, Science Education, and Psychology, which focuses on the study of learning issues, have created a field of study that in recent years has been identified as Early Childhood Science Education [1–4]. In this field, a wide range of questions are raised, with one of the most prominent being the processes by which children up to 8 years of age discover and conceptualize natural phenomena. Thus, one research topic that was predominantly developed was the tracing of young children's mental representations of specific natural phenomena [5–8]. Based on these findings, diverse efforts that fit into different theoretical frameworks on learning and teaching were made to create appropriate teaching activities. At the core of these activities was the transformation of the initial children's mental representations [9,10].

2. Theoretical Background and Literature Review

Within the context of a particular framework which focuses on the development of teaching activities for the transformation of children's mental representations, it was found that under certain conditions, it is possible to form in the minds of young children thought patterns that go beyond their mental representations. These thought patterns are well known in the academic literature as precursor models. In particular, precursor models are entities of thought that, from a structural point of view, are stable and compatible with school scientific knowledge. That is, they are located between mental representations and school knowledge. From a functional point of view, they allow children to exploit certain capabilities of real mental models in order to make descriptions based on appropriate variables, explanations of a certain level, and predictions of the evolution of phenomena and changes [11].

Undoubtedly, a fundamental question that has arisen is the way in which precursor models in Early Childhood Science Education can be constructed. The main orientation of such a research perspective systematically utilized a fundamental sociocognitive tradition of Science Education which seeks to design and implement instructional activities that aim to address children's cognitive difficulties. However, given that the discussion concerning early precursor models is rarely new, it makes sense that the research is actually guided through all directions that can promote effective instructional interventions [11]. Thus, from a sociocultural perspective [12–16], in recent years, a number of researchers have attempted to use narrative and storytelling approaches in the development of scientific thinking and learning in early childhood. Narrative and storytelling approaches, with which both young children and their teachers are well acquainted, can act as the bridges that will connect in a concrete way the imagination and emotions of young children with their initiation to concepts and phenomena of the Natural Sciences [17]. Along this direction, it would be interesting to turn our efforts into the construction of precursor models for early childhood education pupils.

Research that has a sociocognitive orientation has highlighted the possibility of constructing precursor models for young children regarding diverse phenomena such as floating and sinking [18], air [19], inheritance [20], etc. Among the phenomena that have been studied, it has emerged that certain thermal phenomena, such as for example water state changes, are favorable for the construction of precursor models in young children's thinking [21]. Indeed, it seems that the determinant causal factor in simple thermal phenomena, which is the heating or cooling of materials, is conceptualized by young children as a fundamental element for creating changes that acquire in their thinking a certain regularity. Having this in mind, we turned to the study of expansion and contraction phenomena.

The way in which children of different ages perceive the phenomenon of thermal expansion and contraction of metals has not been extensively studied. This phenomenon has specific characteristics which deserve to be highlighted. Firstly, its explanation from a physicist's point of view requires a complex study and understanding of the motion of the structural elements of metal at the microscopic level, an approach that is clearly not appropriate in an early childhood context. What is more, at the macroscopic level, which is counted as the appropriate level for teaching young children, there still seems to exist a peculiarity. That is, the simple experiments with which the study of the phenomenon is supported do not have spectacular and easily measurable results. For example, a sphere heated over a camping gas flame expands so slightly that this change is hardly visible at all. Its expansion can be inferred only by the inability of the sphere to get through a hole from which it previously could pass marginally. Therefore, since younger children have no everyday experience of this behavior of matter, approaching the phenomenon requires the formation of mental processes that deal with the relationship between heating and expansion in an abstract way.

These particularities act as a major obstacle to the conceptualization of the phenomenon, even for older children. A small number of relevant studies on 11–18-year-old students highlighted the difficulties of the construction in students' thinking of a model that approaches school-scientific knowledge about expansion and contraction, either at a macroscopic or microscopic level. Crespo & Pozo [22] point out that students are able to use microscopic terms in their discussions of the phenomenon, but their interpretations are often limited to attributing macroscopic properties to particles in the microcosm, paralleling the motion of a particle as the motion of a sphere.

In a study with children aged 11–12 years, Lee et al. [23] found that children's initial ignorance of the phenomenon was easily addressed at the macroscopic level, while barriers remained severe when the discussion turned to the microscopic level. To put it differently, children could easily understand heating/cooling as a cause of the expansion/contraction of a metal but found it difficult to give explanations based on molecular motion. Of course, the microscopic approach to the phenomena of expansion and contraction is far beyond the reach of the minds of young children. That is why, in the few studies of these phenomena in early childhood education, the questions remain at the macroscopic level. Indeed, a study with young children investigated alternative ideas of preschool children with and without learning difficulties, aged 4–7 years old, on contraction and expansion [24]. In particular, with the usage of structured digital tools, the participants were asked to communicate their ideas about what would happen if a metal ball and a metal tube were heated for a long time. Quite interestingly, the vast majority of them gave a response compatible with school knowledge.

Drawing from an empirical study of Author et al. [25], where the expansion and contraction of metals was studied with preschool children, the question of the possibility of the construction of a precursor model of that phenomenon was raised. The study was carried out in four stages, during which predictions and explanations for the simple cases of thermal expansion and contraction were explored. Discussions with children showed that a considerable number of preschoolers were able to benefit from their involvement in specific teaching processes. It also seemed that children were able to enter a cycle of activities that led to the construction of a precursor model. However, it should be noted that the approach that was adopted was exploratory and developed in a limited area of research.

The current study aims to investigate the possibilities of forming in 4–6-year-old children's minds a precursor model for the expansion and contraction of metals. The strategy that was adopted combines two distinct theoretical frameworks. One derives from a sociocognitive perspective, which leads to activities aimed at overcoming cognitive barriers. The other is inspired by a sociocultural framework and exploits a storytelling approach, which stimulates the imagination, attention, and interest of young children. Along the line of the construction of a precursor model, the current study seeks to answer the following two research questions.

(RQ1) What are the mental representations of preschoolers about the thermal expansion and contraction of a metal sphere?

(RQ2) Having followed a specially designed didactic intervention based both on the narration of a fairy tale and on simple experiments, does the transformation of the initial mental representations take place? That is, to what degree are children able to predict and interpret the thermal expansion and contraction of various metal objects and thus construct a precursor model in their thinking?

3. Materials and Methods

3.1. Participants

The sample included 36 children (20 boys and 16 girls) aged 4 to 6 (average age: 4 years and 11 months) from a public nursery school in Patras, Greece. For all the participants, special permission was requested from their parents. The children were invited to play with the researchers and participated in the research procedure. These children had not previously attended any organized educational activities on the thermal expansion and contraction of metals. All socioeconomic levels (low, middle, and high) were represented in the sample.

3.2. The Procedure

The research took place in three phases: pretest, teaching intervention, and posttest. During the pre- and posttests, the children's reasoning was recorded through individual semistructured interviews [26,27]. Each of these interviews lasted about 10 min and took place in a specially designated area of the kindergarten. The pretest was performed 2 weeks before the educational interventions, while the posttest was administered 2 weeks after the interventions for all subjects. Data analysis was based on transcripts of recordings as well as personal observation protocols that allowed any relevant nonverbal responses to be encoded.

In the design of the current study, we did not propose a comparison of the results among the experimental and control groups. Despite the undoubted importance of such a methodological choice, in recent years, we have avoided including it in our research design because we noticed it consistently led to a statistically significant performance in favor of the experimental groups (for example, [28]). Indeed, in the perspective of constructing a precursor model, the organization of the teaching intervention is based on conditions for creating interactions that are systematically oriented towards addressing the already established student's cognitive barriers, so they tend to outperform other teaching interventions. This certainly does not mean that other effective learning strategies do not need to be constantly explored, but as the theoretical framework is gradually developed, the effort is mainly directed toward exploring both the qualitative characteristics of the interactions and the selection of appropriate pedagogical material as well as teachers' training.

The Ethics Committee of the Department of Educational Sciences and Early Childhood Education of the University of Patras approved the study and consent procedures (approval No: 9/21.2.2023).

3.3. Device and Pretest Interviews

The pretest was performed using a cubic expansion device (Figure 1).

Figure 1. The cubic expansion device was used in all phases of the procedure.

During the pretest, a detection of the children's mental representations of the expansion of the sphere was performed. Having done this, the cubic expansion device was presented to the children, who were able to observe that the sphere could pass through the hole. Immediately afterwards, the children were asked to predict whether the ball would still be able to pass through the hole as soon as it was either overheated or cooled. Based on the children's responses, a discussion ensued, during which the children were asked to provide clarification.

3.4. Teaching Intervention

The teaching intervention was carried out in the classroom and was based on the narration of an improvised tale. In this tale, the phenomena of contraction and expansion of a metal key were apparent through the capability of the key to enter the lock as soon as it was cold but not when it was hot (see Appendix A). Having initiated a discussion with children in order to get their first ideas about this 'peculiar' phenomenon, the narration was stopped, and all children were invited 'to play' with such a concrete metal key.

At this stage, the cubic expansion and contraction device of a sphere was presented to children, who were asked to make a prediction for the case of heating the sphere. Immediately, the experimental confirmation was followed (Figure 1). The experiment gave us the opportunity to discuss with the children the effect of heating on a metal sphere and to address the phenomenon of expansion. Having finished the discussion, children were asked to predict whether the sphere would pass through the ring as soon as it was cool. Finally, the experimental confirmation took part by entering the sphere in a glass of cold water and finding that it could still go through the hole.

Having finished the experimental part, the teaching intervention focused again on the narration of the improvised tale. Here children had to deal again, from a new perspective this time, with the 'peculiar' behavior of the metal key which, once heated, could not fit in the lock.

3.5. Posttest Devices and Interviews

During the posttest, interviews that encompassed three diverse experimental activities were conducted with the children.

(1) During the posttest interview, the students were asked to make predictions about the passage of the sphere through the hole as soon as it was either heated or cooled in order to check whether they had changed their initial representations, especially for the sphere they had observed during the didactic intervention (Figure 1). Justifications were requested for these predictions.

(2) In addition, children were presented with a surface expansion device (a metal disc passing through the hole of a plate) (Figure 2). Children were asked to make predictions about what would happen as soon as the disc gets either heated or cooled and clarify their predictions. Later, experimental confirmation took place, and the results were clearly justified.

Figure 2. The surface expansion device that was used during the posttest.

(3) Finally, children were presented with a linear metal expansion device (a metal rod which, as soon as it was heated, expanded and was moved to a connected indicator) (Figure 3).

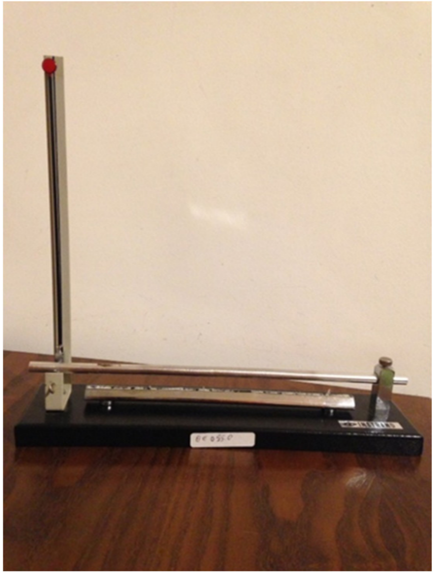


Figure 3. The linear expansion device that was used during the posttest.

Children were asked to make predictions about what would happen as soon as the metal rod was either heated or cooled and clarify their predictions. Later, experimental confirmation took place, and the results were clearly justified.

Finally, the children were asked to think in general terms about the effect of heat on metal (iron) objects without referring to a specific object.

3.6. Data Analysis

Content analysis was used as the method to deal with the data. Along with the theoretical framework of constructing a precursor model, the categories of analysis of student responses were based on the distance between children's reasoning and the school's scientific knowledge. Thus, the mental representations identified in the dialogues with children were classified into the following three categories:

(a) *Sufficient* responses are those in which children predict and explain the expansion or contraction of objects by relating the changes in their thermal state with changes in their volume, surface area, or length.
(b) *Intermediate* responses are those in which children, while predicting the changes in the behavior of metal objects due to thermal changes, fail to relate them to changes in their volume, surface area, or length.
(c) *Insufficient* responses are those in which children neither predict the correct effect of heating or cooling on the metal objects nor give satisfactory justification for their answers.

To investigate the progress of students after the teaching intervention, we carried out a series of nonparametric tests, specifically the Wilcoxon signed-rank test. This is utilized to test differences among two dependent groups when the measurements (in our case three-point scale) are ordinal [29]. In each pair of comparisons, we compared the students' responses separately for questions about two conditions (expansion and contraction). Particularly, we compared the pretest with the sphere with the posttest of the different materials after the intervention.

4. Results

In what follows, the data collected during the pretest and posttest are presented. In particular, for each task, categories of responses are illustrated along with typical children's responses as well as tables of frequencies of these responses.

4.1. First Research Question

Task 1.1. The thermal expansion of the sphere.

A cubic expansion device was presented to children (Figure 1). The children were asked: 'Could you see this metal sphere? It can easily get through this hole. What do you think will happen to the sphere if it gets hot?' Children were asked to explain and justify their answers. Their responses were classified into two distinct categories.

a. *Intermediate responses*. Here were classified responses that, while predicting that the heated sphere would not pass through the hole, they did not make any connection to expansion. For example: Student 8 (S8), '*It will not pass*. . . *because it will melt*. . . *it well gets soften*'.
b. *Insufficient responses*. Here were classified responses that did not predict that the sphere would not pass through the hole and consequently were not compatible with scientific knowledge. Here, the explanations given by the children were based on their everyday experiences; ideas such as that it will melt, burn, just heat up etc. were brought out. For example, S9, '*I think it will pass*. . . *Because when we heat it up it doesn't melt, it gets nothing. The wax melts*. . . *yes, the wax can melt!' Yes, wax melts*'. In this category were also placed children's responses who stated that they do not know or cannot make any prediction.

Task 1.2. The thermal contraction of the sphere.

Having finished the discussion about the effects of heating on the sphere, children were asked to predict whether the sphere would pass through the hole as soon as it was cooled instead of heated. They were also asked to provide a justification for their answer. Here children's responses were classified into three distinct categories.

a. *Sufficient responses*. In this category, only one response was classified, which was characterized by a satisfactory prediction and interpretation: S27, '*It will get through the hole*. . . *because it will become smaller*. . .'.
b. *Intermediate responses*. Here were classified responses that, while predicting that the cooled sphere would pass through the hole, they did not make any connection to contraction. For example, S13, '*It will get through*. . . *it will cool down*'.
c. *Insufficient responses*. Here were classified responses that did not predict that the sphere would pass through the hole. The explanations given here were mainly based on children's everyday experiences. For example, S20. '*It will not get through... it will become a big sphere*'. In this category were also placed children's responses who stated that they do not know or cannot make any prediction.

Table 1 shows the frequencies of children's responses as well as the classification of each child in one of the three distinct categories in the two pretest tasks.

Table 1. Children's frequencies of children's responses to the two pretest tasks.

	1.1—Expansion	f	1.2—Contraction	f
Sufficient		0	27	1
Intermediate	1, 6, 8, 13, 18, 23	6	6, 11, 12, 13, 14, 15, 16, 17, 21, 22, 23, 31, 34, 35, 36	15
Incompatible	2, 3, 4, 5, 7, 9, 10, 11, 12, 14, 15, 16, 17, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36	30	1, 2, 3, 4, 5, 7, 8, 9, 10, 18, 19, 20, 24, 25, 26, 28, 29, 30, 32, 33	20

4.2. Second Research Question

The posttest comprised six diverse tasks. The first two were the same that were presented to children during the pretest and dealt with the expansion and contraction of a metal sphere. These tasks led to two simple experiments which were implemented throughout the teaching intervention. Therefore, children not only dealt with the questions of the task on a theoretical base but also saw and discussed in practice the effects of heating and cooling of the sphere. Of course, this strong empirical content may have influenced children's responses without necessarily taking place in the transformation of their mental representations expressed during the pretest. Therefore, in addition to these two tests, four other tasks were presented to children with the aim of determining whether they were able to predict and explain the expansion of other metal objects which, in fact, do not have the isometric growth of the sphere in all three dimensions.

Task 2.1. The thermal expansion of the sphere.

Using the cubic expansion (Figure 1), the children were asked to express their view of whether the sphere that was observed to get through the hole would continue to pass when it gets heated. Drawing from the discussion with the children, their responses were classified into the following three categories.

a. *Sufficient responses*. Here were classified responses in which the children predicted that the heated sphere would not get through the hole due to some kind of inflation caused by the heating. For example, S1, '*It will not get through... it will heat up and get bigger, so it will not be able to get through the hole*'.
b. *Intermediate responses*. Here were classified responses that, while recognizing that the hot sphere would not pass through the hole, were not based at all on the sphere's inflation. For example, S17, '*It will not get through because it will get soften*'.
c. *Insufficient responses*. Here were classified those responses that recognized that the sphere would get through the hole. For example, S10, '*It will get through the hole because it is small*'.

Task 2.2. The thermal contraction of the sphere.

Having completed the task on expansion, children were asked to express their view and justify whether the sphere would pass through the hole when it cooled. Children's responses were classified again into three categories.

a. *Sufficient responses*. Here were classified responses that predicted that the sphere would be able to get through the hole. On the basis of all answers was the decrease in the volume of the sphere. For example, S9, '*It will pass... It will freeze and shrink*'.
b. *Intermediate responses*. Here were classified responses that, while recognizing that the cooled sphere would pass through the hole, were not correlated with the reduction in the volume of the sphere. For example, S17, '*It will get through the hole... it will freeze and get through*'.
c. *Insufficient responses*. Here were classified responses that did not recognize that the sphere would get through the hole. For example, S25, '*It will not pass... because it will be cooled*'.

Table 2 shows the frequencies of children's responses to posttest tasks 2.1 and 2.2.

Table 2. Frequencies of children's responses to posttest tasks 2.1 and 2.2.

	2.1—Expansion	f	2.2—Contraction	f
Sufficient	1, 2, 3, 5, 6, 7, 8, 9, 12, 13, 14, 16, 18, 23, 25, 26, 27, 30, 31, 33, 34, 35, 36	23	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15, 18, 23, 27, 30, 31, 32, 33, 35, 36	22
Intermediate	4, 15, 11, 17, 19, 20, 28, 29, 32	9	12, 16, 17, 19, 20, 21, 24, 26, 28, 29, 34	11
Insufficient	10, 21, 22, 24	4	11, 22, 25	3

Task 2.3. The thermal expansion of the disk.

The children were then shown the surface expansion device (Figure 2). Initially, they were asked to test the device, observing that the disc could pass through the hole in the plate. They were then asked to predict and justify their answer of whether the disc would continue to be able to get through the hole as soon as it got heated. Children's mental representations led to responses, which were classified into three distinct categories.

a. *Sufficient responses*. Here were classified responses in which the children predicted that the disk would not pass through the hole in the plate when it gets heated due to the increase of the surface of the disc. For example, S16, '*It will not be able to get through... It will heat up and then become bigger so it will not be able to pass through the hole*'.
b. *Intermediate responses*. Here were classified responses in which the children, while predicting that the disk would not pass through the hole in the plate, did not make any connection between the heating and the increase in the surface of the disk. For example, S17, '*It will not be able to pass... it will heat up and become soften*'.
c. *Insufficient responses*. Here were classified responses in which it was predicted that the disc would pass through the hole. For example, S10, '*It will go through... It fits to the hole*'. In this category were also placed children's responses who stated that they do not know or cannot make any prediction.

Task 2.4. The thermal contraction of the disc.

Having completed the task regarding disc expansion, children were asked to predict and explain whether the disk would pass through the hole in the plate as soon as it was cooled. Children's responses were classified into three distinct categories.

a. *Sufficient responses*. Here were classified responses in which the children predicted that the disk would pass through the hole in the plate and justified their answers in terms of the reduction in the volume of the disc. For example, S6, '*It will go through. It will get smaller and so it will go through... because it will freeze and become its normal size*'.
b. *Intermediate responses.* Here were classified responses in which children, while predicting that the disc would pass through the hole in the plate, did not make any connection between the cooling and the reduction in the surface of the disk. For example, S19, '*It will go through... because it wants to get in*'.
c. *Insufficient responses*. Here were classified responses in which it was predicted that the disc would not pass through the hole by expressing thoughts that were far from thermal changes. For example, S22, '*The disc will turn blue and red because it changes colour*'. In this category were also placed children's responses who stated that they do not know or cannot make any prediction.

Table 3 shows the frequencies of children's responses to posttest tasks 2.3 and 2.4.

Table 3. Frequencies of children's responses to posttest tasks 2.3 and 2.4.

	2.3—Expansion	f	2.4—Contraction	f
Sufficient	1, 2, 3, 5, 6, 7, 8, 9, 12, 13, 14, 16, 18, 23, 25, 26, 27, 30, 31, 32, 33, 35, 36	23	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 14, 15, 18, 23, 27, 30, 31, 32, 35	19
Intermediate	15, 19, 28, 29, 34	5	11, 12, 13, 16, 17, 19, 20, 21, 24, 26, 29, 33, 34, 36	14
Insufficient	4, 10, 11, 17, 20, 21, 22, 24,	8	22, 25, 28	3

Task 2.5. The thermal expansion of the rod.

Having finished the discussion regarding the expansion and contraction of the disc, the students were shown a linear metal expansion device (a metal rod which, as soon as it gets heated, expands, and moves a connected indicator) (Figure 3). Children were asked to predict and explain what would happen to the rod if it was heated. Children's responses were classified into three distinct categories.

a. *Sufficient responses.* Here were classified responses in which it was predicted that the rod would increase in length. For example, S12, '(The rod) *will become long... because it will get heated*'.
b. *Intermediate responses.* Here, only one child predicted that the rod would increase in length, without making any connection between the increase in length and heating though. For example, S8, '*It will become bigger... (why?) I don't know...*'.

c. *Insufficient responses*. Here were classified responses in which it was not predicted that the rod would increase in length. For example, M17, '*It may get soften and do nothing*'.

Task 2.6. The thermal contraction of the rod

Having completed the task regarding rod expansion, children were asked to predict and explain what would happen to the rod as soon as it was cooled instead of heated. Children's responses were classified into three distinct categories.

a. *Sufficient responses.* Here were classified responses in which it was predicted that the rod would get smaller after it cooled down. For example, S12, '*It will shrink. . . it will get its normal size*'.
b. *Intermediate responses*. Here were classified responses in which, while it was predicted that the rod would get shorter, they did not link the reduction in length to cooling: S8, '*It will get longer. . . (why?) I don't know*'.
c. *Insufficient responses*. Here were classified responses in which it was not predicted that the rod would shrink due to cooling. For example, S15, '*Because it will be big*'.

Table 4 presents the frequencies of children's responses to tasks 2.5 and 2.6.

Table 4. Frequencies of children's responses to posttest tasks 2.5 and 2.6.

	2.5—Expansion	**f**	**2.6—Contraction**	**f**
Sufficient	3, 7, 9, 12, 14, 18, 23, 27, 30, 31, 32, 35, 36	13	3, 6, 7, 9, 12, 14, 18, 23, 27, 30, 31, 32, 35, 36	14
Intermediate	5, 8, 29	3	1, 4, 5, 24, 25, 29, 34	7
Insufficient	1, 2, 4, 6, 10, 11, 13, 15, 16, 17, 19, 20, 21, 22, 24, 25, 26, 28, 33, 34	20	2, 8, 10, 11, 13, 15, 16, 17, 19, 20, 21, 22, 26, 28, 33	15

Task 2.7. Frequencies of children's responses to posttest task 2.7

At the end of the interview, the children were asked '*What. . . would happen to a metal (e.g., iron) as soon as it gets heated*?' This task takes children's thinking into an abstract context as they are not asked about a specific object. Children's responses were classified into three distinct categories.

a. *Sufficient responses.* Here were classified responses in which children predicted that the volume of metallic iron objects would increase. For example, S7: '*All* (iron objects) *will become bigger*'.
b. *Intermediate responses*. Here was exclusively classified the answer of child M5, who while satisfactorily addressing this question, did this by referring to the situations of previous tasks: '*. . .if we warm it up it will not fit. . . it will get bigger*'.
c. *Insufficient responses*. Here were classified responses in which it was not recognized that metal objects swell as soon as they are heated. For example, S1: '*It will get hot and shrink*'.

Table 5 presents the frequencies of children's responses to task 2.7.

Table 5. Frequencies of children's responses to posttest task 2.7.

	2.7—Expansion	**f**
Sufficient	3, 6, 7, 8, 9, 12, 14, 18, 23, 25, 26, 27, 30, 32, 35, 36	16
Intermediate	5, 24, 31,	3
Insufficient	1, 2, 4, 10, 11, 13, 15, 16, 17, 19, 20, 21, 22, 28, 29, 33, 34	17

4.3. Statistical Assessments

Next, the differences in children's responses between the pre- and posttests are studied. Table 6 presents the comparisons of pretest with posttest in each of four cases about expansion. In all cases, the test indicates statistically significant results and at least medium effect size. Therefore, after the teaching intervention, students mainly present cognitive progress.

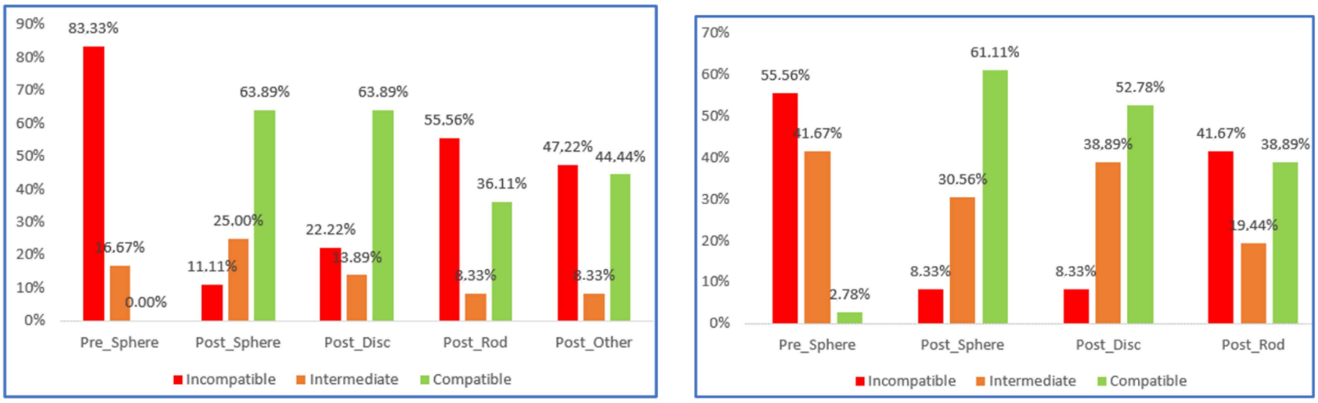
Table 6. Wilcoxon signed-rank test for the pre- and posttest questions about expansion.

Materials after the Intervention	Progress (Posttest > Pretest) N	Stagnation (Posttest = Pretest) N	Retrogression (Posttest < Pretest) N	Wilcoxon Test
Sphere	32	4	0	z = −5.09, p = 0.001, r = 0.60
Disk	28	8	0	z = −4.79, p = 0.001, r = 0.56
Rod	15	18	3	z = −3.31, p = 0.001, r = 0.39
Other	19	15	2	z = −3.79, p = 0.001, r = 0.44

Notes: r = z/$\sqrt{}$(2N) 'Effect size', greater than 0.3 indicate a medium effect, and values greater than 0.5 indicate a large effect [29].

Similarly, Table 7 presents the comparisons of pretest with posttest in each of four cases about contraction. In all cases, the test indicates statistically significant results and at least medium effect size. Therefore, after the teaching intervention, students mainly present cognitive progress.

To depict the previous results, we present a bar chart with the responses of students. As you can mainly see in the two first posttests after the intervention, the students move in more compatible responses and the two conditions. Moreover, at least one in three students seems to be kept at a compatible cognitive level in all cases (Figure 4).



Notes: Expansion Condition

Notes: Contraction Condition

Figure 4. Students' responses distributions in all tests for the two conditions (N = 36).

Table 7. Wilcoxon signed-rank test for the pre- and posttest questions about contraction.

Materials after the Intervention	Progress (Posttest > Pretest) N	Stagnation (Posttest = Pretest) N	Retrogression (Posttest < Pretest) N	Wilcoxon Test
Sphere	27	7	2	z = −4.47, p = 0.001, r = 0.53

Table 7. *Cont.*

Materials after the Intervention	Progress (Posttest > Pretest) N	Stagnation (Posttest = Pretest) N	Retrogression (Posttest < Pretest) N	Wilcoxon Test
Disk	24	11	1	$z = -4.31$, $p = 0.001$, $r = 0.51$
Rod	19	10	7	$z = -2.75$, $p = 0.001$, $r = 0.32$

Notes: $r = z/\sqrt{(2N)}$ 'Effect size', greater than 0.3 indicate a medium effect, and values greater than 0.5 indicate a large effect (Field, 2018).

5. Discussions and Conclusions

In the current study, an attempt was made to explore the possibility of constructing a precursor model in the thinking of 5–6-year-old children for the thermal expansion and contraction of metal objects. The research design began with the mapping of children's mental representations, continued with a complex teaching intervention incorporating an experimental activity in the context of telling a fairy tale, and concluded with the study of potential changes in children's thinking, focusing on the stability of new mental representations compatible with school knowledge.

The first research question was approached through tasks 1.1 and 1.2 of the pretest. In this, children's representations of thermal expansion and contraction in a metal sphere were explored in advance of any teaching intervention. No responses were found in this data that were consistent with school science knowledge. While there were some answers that were characterized by satisfactory predictions, the explanations given did not have any kind of relation between the thermal changes and the expansion or contraction of the metallic sphere. Here the predictions for the effect of heating the sphere were dominated by references to the behavior of other materials (melting, ignition, etc.), while for the effect of cooling, the predictions came mainly from recalling the way the sphere acted before it was heated. These findings are consistent with the data from previous related research [25].

In the second research question, which was approached through tasks 2.1 and 2.2 of the posttest, an attempt was made to find out whether there were changes in children's thinking after the teaching intervention. Quite interestingly, in the posttest, more than 6/10 of the children gave answers consistent with school knowledge. While these changes seem to be spectacular, they should be treated with caution since the children had the chance to view the experimental procedure of expanding and contracting the sphere through heating and cooling, respectively. Anyway, this is the reason why tasks 2.3–2.6 were designed and used. Particularly, in these tasks, the metal objects had other forms than spheres so that it could be monitored whether children actually approached the changes of the objects on the basis of mental representations compatible with school scientific knowledge.

In Task 2.3 and 2.4 it was found that children's responses were at the same level as in Task 2.1 and 2.2. Here again, more than 6/10 children in thermal expansion and 5/10 children in contraction were able to predict and justify the effects of heating and cooling on the flat disc. Our findings here suggest that several children had started to become capable of generalizing their thoughts regarding the heating and cooling effects of the metallic materials, although this could be attributed either to the fact that the children may have been affected by the round shape of the tray or by the fact that the tasks were essentially similar to tasks 2.1 and 2.2.

Our findings are rather confirmed by the results in tasks 2.5 and 2.6 where the number of satisfactory predictions regarding the change in the length of the metal rod was given by more than 1/3 of the children. It was also apparent that several children began to generalize their thoughts regarding the effect of heating or cooling on metal objects since they continued to predict and attribute both expansion and contraction to the change of objects' thermal state. This finding is reinforced by the data in task 2.7 where children were asked to predict, in general, the effect of heating on any metal object without reference to any kind of object that was in their direct perception. Quite interestingly, half of the children (16/36) dealt with the thermal expansion of metals in a scientifically accepted way.

The overall data of the study show that, in line with other simple thermal phenomena, it is possible, to a certain extent, to transform young children's initial mental representations into representations that are compatible with school knowledge [18–20]. In addition, the data is consistent in agreement with the findings of the only study found in the academic literature that dealt with the conceptualization of expansion−contraction in preschool age [25]. Indeed, it appears that a teaching intervention that combines the telling of a fairy tale with the simultaneous performance of specific and targeted experiments that are linked to and serve the narrative creates a favorable educational context for achieving cognitive transformations in young children's thinking. This finding leads to a new field of research on introducing young children to science as it combines two distinct theoretical frameworks. On the one hand, storytelling, which is a traditional practice in preschool pedagogy and on the other hand, the performance of targeted experiments, which is always exploited in science teaching. This is a remarkable perspective that raises new expectations for an effective introduction of young children to science, which of course, needs to be substantiated with empirical data in different subjects. Particularly for the phenomenon of expansion and contraction, it would be particularly meaningful to carry out a research design that would include a comparison with control groups participating in other types of activities.

The findings of the current study highlight the remarkable stability of some children's representations through all posttest tasks. Indeed, nine children (S3, S7, S9, S14, S18, S23, S27, S30, S35) gave satisfactory predictions and explanations in all posttest tasks. This finding underlines the ability of 4–6-year-old children to construct in their thinking mental entities about the phenomena of expansion and contraction that are compatible with school knowledge. Particularly, these entities have the characteristics of a precursor model as they offer the possibility of describing and predicting the evolution of the above-mentioned phenomena. In addition, since the thermal change of metal objects is the only variant that changes during the development of the phenomenon through heating or cooling, a macroscopic explanation was also recorded in discussion with children, which clearly highlights this connection.

However, it is important to define the range of these results, as methodological choices always impose some limitations. First of all, the technique of classifying the whole range of children's answers into three distinct levels (sufficient, intermediate, insufficient) necessarily leads to formulations which, in some cases, may limit the variety and richness of the representations. The categories of this classification, whose effectiveness has been evaluated in a long series of studies related to the understanding of science, seem to be functional since the logic of their constitution derives from the nature of these studies, which are always oriented towards the compatibility of children's reasoning with school scientific knowledge. It is exactly this amplified interest in the 'distance' of children's representations from school scientific knowledge that leads to satisfactory conclusions, at least for the reasonings that are characterized as sufficient or insufficient, since compatibility or incompatibility are identified in a clear and unambiguous way. With regard to intermediate responses, the inclusion of reasonings resulting from different difficulties and obstacles to children's thinking is often found. Therefore, it is a fact that in studies with different theoretical perspectives, it might be useful to study them with a different qualitative analysis. In our research orientation, the intermediate category includes children's responses whose two main characteristics are the following: the limited but partial compatibility with school scientific knowledge as well as the potential for transformation within specific teaching contexts.

Another limitation of the current study is the relatively small sample consisting of almost 36 children. This choice was made due to the fact that the experimental design in three phases within the kindergartens would possibly exhaust the potential of schools to accommodate the researchers. Besides, this sample allowed for both qualitative and quantitative analysis of the research data. However, it is certain that implementing the survey with a larger sample and in differentiated populations (for example, in other countries with different cultural characteristics) would lead to results that are better founded.

The construction of precursor models through a storytelling approach can be a useful approach for developing science activities in early childhood education. In this study, it was shown that children are able to systematically approach a natural phenomenon in an educational context dominated by storytelling. Indeed, our findings allowed us to identify for a number of children the possibility of constructing models compatible with school knowledge, even though this was achieved in a limited learning domain, such as the thermal expansion and contraction of metals. Undoubtedly, this gives us the possibility to try extending the development of this kind of activity in other teaching domains too. In addition, they may prove useful for improving programs in preschool education as well as teacher training [30–33].

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Appendix A

We present here the plot of the storytelling on which the teaching intervention was based.

A mischievous bunny called 'Thermal Expansion', gets into trouble during the winter. One afternoon, having left his house, he wanders off into the snowy forest. In the night he finally finds a little house among the trees and opens the door with a frozen icy key he finds just outside. The next morning, the key that was left all night by the hot and burning fireplace, does not fit into the lock in order to unlock it.

(*At this point the story is interrupted, and the experiments of both expansion and contraction of the metal sphere are presented to all children. In addition, the behavior of the sphere after heating and cooling is thoroughly discussed*).

Immediately afterward, we return to the storytelling and ask the children what can be done to enable the bunny to successfully put the key into the lock and open the door. The children refer to the cooling of the key and the story ends with the confirmation of the solution given by the children.

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