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Effects of Spatial Skill Training on Children's Learning Outcomes

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Introduction

Spatial skills training plays a role in many fields of primary school education, as a facilitator of spatial manipulation of mental imagery (Crescentini, Fabbro, & Urgesi, 2014) or as a predictor of learners' science achievement in STEM disciplines (Carr et al., 2018). Spatial skills are recognized to be of significative importance (Newcombe & Huttenlocher, 2006), especially if spatial experiences are improved into existing curricula rather than as a standalone topic (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2017).

Spatial skills can be improved by training throughout childhood (Harris, Newcombe, & Hirsh-Pasek, 2013); nevertheless, little research is actually developed on spatial skills training in primary school. In particular, the intertwined fields of language comprehension, logical reasoning, and spatial relations recognition skills are still mostly unexplored. This research investigates the role of spatial skills training in providing cognitive support for relating perceptual/abstract dimensions of thinking in different sociocultural contexts.

Perceptual and abstract cognitive processing have been seen as distinct mental activities, rooted on different representational systems (Dove, 2009). Embodied cognition instead researches on how human thinking and behavior are influenced by bodies and contexts. Abstract representations may be then linked to perceptual and/or motor representations (Prinz, 2002): in embodied cognition view, concepts are grounded in perception and action (Glenberg, 1997) and higher mental functions are linked to basic cognitive and neurobiological mechanisms. Research has demonstrated that symbolic representations – which do not concern only language, but also maps, diagrams, sketches, and graphs – show relations between perceptual and abstract processing through the use of space[1].

Symbolic representations support indeed spatial learning and spatial metaphors of thinking. Spatial representations can contribute to organize, express, and understand the logical relations

[1] Spatial correlations between perceptual and abstract processing are supported by experimental studies in which spatial perceptual features may influence language comprehension as it is linked to sensorimotor mechanisms (Vukovic & Williams, 2015). The cognitive use of reference frames (Acredolo, 1981) and the individual preferences in their spatial adoption may impact the embodiment of personal different perspectives in language comprehension tasks. Learners develop spatial language in correlation with corresponding conceptual representations of space (Gentner, Özyürek, Gürcanli, & Goldin-Meadow, 2013); then, training the role of spatial words and terms in cognitive tasks may enhance learners' spatial skills. In any case, a correlation between perceptual/abstract processing and representations mechanisms is evidenced as concerns the linked fields of space and language.

not only of the explicit, but also of the implicit[2] dimension of thinking[3]. Patterns of connection between implicit/explicit can be expressed by simple models of spatial representations. In the basic logic theory (Santoianni, 2011), the most suitable transitional format between implicit and explicit is indeed supposed to be spatial representation, which sustains basic logic processing.

In this research, the intertwined fields of language comprehension and spatial representations are related to the fields of logical reasoning and spatial relations recognition skills. The hypothesis is that spatial skills training – if applied to the field of logical reasoning, as concerns in particular the implicit/explicit processing of basic logic (Santoianni, 2014, 2016) – can play as a booster to improve perceptual/abstract processing and the recognition of spatial relations. The research objectives are to evaluate the role of spatial skills training in enhancing learners' performances in tasks involving basic logical processing and comprehension, representation, and association activities of linguistic categories and spatial relations.

In the basic logic theory, spatial dimension has indeed a key role in relating implicit/explicit levels of cognition. Basic logic are abstract categories to be intended as concept-structuring criteria which can be spatially represented and are linked to perception and to implicit/explicit dimension: *add*, integration; *chain*, consequence; *each*, individuation; *compare*[4], comparison; *focus*, derivation; and *link*, correlation. *Chain*[5], consequence and *focus*[6], derivation basic logic have been used here to investigate their role in spatial skills training. Research training tasks have been selected and designed in relation to this conceptual framework:

- the recognition of spatial relations has been studied through activities of growing sequencing, spatial proportions, and association of numbers and geometries (*pretest* 0_1 – Appendix A); activities of disembedding shapes, recognizing and individuating them (*test* A_1 – Appendix B); activities of identifying linguistic categories as concepts structuring criteria and associating them to basic logic (*test* A_1, A_3, A_5, A_{5bis} – Appendices B, C, D, E);

[2] The implicit is an unaware prototypal processing which operates as a default level underlying all cognitive activity. It has been considered in a continuous cognitive collaboration with the explicit (Reber, 1989, 1992, 1993).
[3] At a phylogenetic level, prototypical knowledge has developed adaptive implicit spatial mappings as precursors of explicit linguistic thought (Siegler, Adolph, & Lemaire, 1996). Nowadays, learning is considered to be related to non-linguistic internal mental images, with a spatial structure (Entwistle, Smith, 2002) which can be stored in specifically spatial representative formats (Robinson, Robinson, & Katayama, 1999). At the same time, schematic spatial representations (diagrams) have been linked to explicit processing (Larkin, Simon, 1987) and graphic organizers have been defined as visual and spatial patterns which play a significative role in structuring explicit knowledge contents (Clarke, 1991).
[4] Spatial learning has also been related to comparative thinking, which outlines the common relational structure between different concepts through analogies and similarities, aiming to point out key comparisons (Newcombe, 2010). Analogists have indeed suggested that learners map the relational structure from one domain to another (Reese, Pawluk, & Taylor, 2016).
[5] Implicit logical relationship underlying *chain* basic logic is the sequence of several conceptual units. Sequence means the concatenation of two or more conceptual elements linked by relationships of consequence (Santoianni 2014).
[6] Implicit logical relationship underlying *focus* basic logic is the derivation of more conceptual units from each other. Derivation means the inductive and deductive process according to which a conceptual element can be in a derivative relationship with others (Santoianni 2014).

- the perceptual/abstract processing has been deepened through activities of reading comprehension, cutting texts' labels, and filling them into associated shapes designed as *chain* and *focus* basic logic (*test* $B_1/_{bis}$, $B_2/_{bis}$, $B_{3A}/_{bis}$, $B_{3B}/_{bis}$, $B_4/_{bis}$ – Appendices F, G-H, I-L, M-N);
- the implicit/explicit processing has been present overall in the selected activities because to recognize spatial relations applied to basic logic means to understand the reciprocal relation between perceptual implicit processing and abstract explicit thinking. Implicit level is indeed considered narrower to the perceptual field, while explicit is linked to verbal and abstract.

In this study, spatial dimension is analyzed as applied to integrative, consequential, individuational, derivative, and correlative thinking[7], and not only to comparative thinking and analogical reasoning, which is spontaneously developed by children since early infancy (Goswami, 1996). All these kinds of reasoning require fluid intelligence (Cattell, 1963), which means speed and accuracy of abstract reasoning, in particular for novel problems (Sternberg, 2005). The development of fluid intelligence can enhance learners in relating perceptual and abstract processing by leveraging on spatial skills training of logical reasoning. Spatial skills have been interpreted as intrinsic-static skills (the processing of shapes by coding their spatial features) and intrinsic-dynamic skills (the manipulation or transformation of shapes) (Uttal et al., 2013).

Material and Methods

The research has combined qualitative and quantitative methods. The qualitative method was mainly based on the basic logic theory (Santoianni, 2011, 2014, 2016). The quantitative methods used statistical evidence to analyze significant differences between the various groups. Data collection methods have been questionnaires, forms, and face-to-face interviews.

1.1 Participants

The experimental level involved 63 students of the fifth-year (58.7% males, 41.3% females), aged 9 to 11 years old (1.6% of 11 years, 84.1% of 10 years, 14.3% of 9 years). Experimental (training) groups (EG) and control groups (CG) have been selected through non-probability sampling. The method of random sampling was voluntary (Paoletti, 2000). The sample has been assigned within four parallel classes of two public primary schools of Naples, Italy–Cimarosa (29 students) and Mallardo (34 students). The chosen schools had different sociocultural and economic backgrounds. Cimarosa (S_1) is located in Municipality 1, a socially and economically advantageous neighborhood, while Mallardo (S_2) is located in Municipality 8, a socially and culturally disadvantaged context. The students' parents were informed of the experimental task their children were asked to perform and gave their consent.

1.2 Procedure and Materials

The experimental procedure (Table 1) started with a preliminary phase in which all groups

[7] In the basic logic theory, the class of union includes the basic logic of integration and consequence; the class of separation includes individuation and comparison; the class of correlation includes derivation and correlation (Santoianni 2011, 2014).

(training and control) have been tested together in the two schools.

Table 1
Procedure

starting phase		0_1	appendix A	skills
	task	spatial sequences, spatial and numerical proportions, geometric shapes		sequencing proportions association
phase A		A_1	appendix B	
	task	find and color geometric shapes in a complex display		disembedding recognition individuation
		A_3	appendix C	
	task	match a sentence to the shape that could best represent it		link comprehension logical association spatial relations
phase B		B_1/bis	appendix F	
	task	read a given text on Roman society and on Family		text comprehension
EG only		B_2/bis	appendices G-H	
	task	complete a logic shape filling its empty spaces with labels–scaffolded		spatial relations logical association link representation
EG only		B_{3A}/bis	appendices 8-9	
	task	read a text on Roman republic and on Family added with spatial terms		text comprehension spatial language
		B_{3B}/bis	appendices 8-9	
	task	read a standard text on Roman republic and on Family		text comprehension
		B_4/bis	appendices 10-11	
	task	complete a logic shape filling its empty spaces with labels–alone		spatial relations logical association link representation
final phase		A_5/bis	appendices D-E	
	task	match a sentence to the shape that could best represent it		link comprehension logical association spatial relations

Since students were coming from socially, culturally, and economically different school backgrounds, the aim of the pretest (see Appendix A) was to evaluate if the selected sample could be considered homogeneous as concerns spatial relations recognition skills[8].

Task pretest 0_1 (Appendix A). The task consisted in guessing spatial growing sequences, spatial proportions, and sequences of numbers according to geometric shapes. The task has been structured as a multiple-choice assessment. Score has been collected according to a proportional metric for quantitative discrete variables[9].

The experimental phase A consisted in two tasks of intrinsic spatial relations (Uttal et al., 2013; Newcombe & Shipley, 2015; Hodgkiss et al., 2018). The task test A_1 (see Appendix B) asked learners to find geometric shapes hidden in a complex display (disembedding). In order to prepare learners to the next step, this task was followed by a discussion in classroom on the chance to associate a concept to a shape which could better express it.

Task test A_1 (Appendix B). In this perceptual semi-structured recognition task, learners had to find geometric shapes in a complex display by coloring them. Score has been calculated according to a not metric ordinal scale for qualitative categories[10].

Task test A_3 (Appendix C). In this perceptual and conceptual task, learners had to understand the text of common sentences, to identify the hidden logical relations as structuring criteria between concepts, and to match a sentence on common concepts to the shape that could more appropriately represent these logical relations, among some given spatial representation of basic logic. Since not all possible shapes may represent a concept, learners discussed in classroom about the chance that a shape could represent more than one concept. In the final evaluation phase, this task has been repeated as re-test A_5 (Appendix D) and re-test A_{5bis} (Appendix E). A structured assessment by correspondence was chosen for test A_3 and re-test $A_5/_{bis}$, which is a comparison test in which the elements of two data series are asked to correspond in biunivocal

[8] Spatial relations recognition skills may be learned and trained in educational contexts, but they may be also competencies of visuo-spatial learners.

[9] Numerical values have been scaled as follows: 3 figures recognized on 3, score 5; 2 figures, score 4; 1 figure, score 3; 0 figures, score absolute zero.

[10] Even if the used scale could have been here an ordered list of values to establish a classification based on levels, in this task it wasn't relevant to the purpose of the experimental session to say "how much" the levels were distant from each other. An ordinal scale has then been instead used because it is a mutable whose modes are logically sequential (ascending or descending) attributes, but it is not possible to measure the distance between them.

correspondence[11]. Results of test A_3 and re-test $A_5/_{bis}$ have been scaled according to a proportional metric for quantitative discrete variables[12].

Tasks re-test $A_5/_{bis}$ (Appendices D-E). In these perceptual and conceptual tasks, it was required to match a sentence on common concepts to the shape that could best represent it among some given spatial representation. The foreseen connections between phrases and shapes were the same of test A_3, but shapes' appearance was more articulated. Re-test A_{5bis} has been instead designed without modifying the shapes compared to test A_3, but only simplifying the phrases to be linked.

The experimental phase B has been based on the basic logic theory (Santoianni, 2011, 2014, 2016) as a qualitative method, which basic logic can be considered concept-structuring criteria. This phase has concerned four tasks of intrinsic and dynamic spatial relations (Uttal et al., 2013; Newcombe & Shipley, 2015; Hodgkiss et al., 2018). The core of this phase was to analyze if the recognition of basic logic processing underlying linguistic comprehension, and its association to the related spatial representation, could facilitate learners in managing perceptual/abstract processing. The tasks $B_1/_{bis}$ (see Appendix F) were developed to explain the chosen disciplinary content to learners and to scaffold them on its comprehension.

Tasks $B_1/_{bis}$ (Appendix F)**.** The exercise was to read together in classroom a text on Roman society (from a primary school book) and on Family (designed by researchers).

The tasks $B_2/_{bis}$ (see Appendices G-H) consisted in completing a shape by filling its empty spaces with given labels selected from the curricular text and the extra-curricular story of tasks $B_1/_{bis}$. Only experimental groups have been trained with scaffolded tasks $B_2/_{bis}$.

Tasks $B_2/_{bis}$ (Appendices G-H). The exercise was only for experimental groups and consisted in a scaffolded task in which learners had to complete a shape filling its empty spaces with given labels selected from a curricular formal text on Roman society and from an extra-curricular informal story on Family. The shape was designed according to the *chain*, sequence and *focus*, derivation basic logic.

Exercises $B_{3A}/_{bis}$ (see Appendix I) – two reading tasks foreseen to explain the chosen disciplinary content to learners – have been customized for experimental groups by adding spatial terms to the texts, while control groups' texts remained unchanged from the original in exercises $B_{3B}/_{bis}$ (see Appendix L). Here learners have been asked to cope with a double effort, to understand disciplinary content while strengthening spatial skills and to acknowledge daily life experienced situations while focusing on spatial organization.

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[11] Usually, in order to avoid that–after the possible arrangement of all the combinations, except the last one–the last one is placed in interlocking for lack of alternatives, the number of terms of the second series is defined as greater than that of the first one. In the specific case of this experimental session, it was thought that for children the difference between the two series was a further difficulty not to be added. For this reason, the two series (forms and sentences) have been designed in an equal number. From a logical point of view, however, whoever guesses the correspondence between five out of six combinations, must also guess the sixth combination for lack of alternatives. It was therefore preferred to apply the correction of not considering the variable of five combinations on six, which in fact as expected has not occurred. A point was therefore assigned for each exact correspondence, except for the case of five correspondences which has been not calculated, as it was not fully evaluable, while the maximum of points (5) has been assigned to the correspondence of six out of six, which also includes that of five items out of six with no alternative for the sixth choice.

[12] Numerical values have been attributed to six different levels of expertise as follows: 6 figures well associated with 6 phrases, score 5; 4 figures, score 4; 3 figures, score 3; 2 figures, score 2; 1 figure, score 1; 0 figures, score absolute zero.

Tasks $B_{3A}/_{bis}$ and $B_{3B}/_{bis}$ (Appendices I-L). The exercise $B_{3A}/_{bis}$ was only for experimental groups and involved the reading of texts on Roman Republic (from a primary school book) and on Family (designed by researchers) re-written in order to add spatial terms to the texts, while in exercise $B_{3B}/_{bis}$ the texts on the same topics were instead unchanged for control groups.

The tasks test $B_4/_{bis}$ (Appendices M-N) first required learners to understand the texts to be read and to identify the given labels as abstract linguistic categories of the related concepts. Then, learners had to recognize the structuring logic at the base of the spatial relations joining the linked parts of the shapes in order to fill in their empty spaces.

Tasks test $B_4/_{bis}$ (Appendices M-N)**.** The task was not scaffolded by teachers. Learners had to complete a shape filling its empty spaces with given labels selected from a curricular formal text on Roman Republic and from an extra-curricular informal story on Family. The shape was designed according to the *chain*, sequence and *focus*, derivation basic logic of the basic logic theory. Test $B_4/_{bis}$ has been designed as a structured assessment by completion, in which results have been scaled according to a proportional metric for quantitative discrete variables[13].

In the final evaluation phase, the task of test A_3 has been repeated twice in the follow-up re-test $A_5/_{bis}$. Re-test A_5 was more complex than test A_3 because shapes' appearance was more articulated, even if the foreseen connections between phrases and shapes were the same. Re-test A_{5bis} was instead designed simplifying the phrases to be connected, without modifying the shapes to be related to them, in order to obtain a simpler level task.

1.3 Design

Research hypothesis was that spatial skills training in different environmental contexts can play as a variable booster for learners aged 9 to 11 years old to improve their perceptual/abstract and implicit/explicit processing when performing in tasks involving basic logical processing and comprehension, representation, and association activities of linguistic categories and spatial relations. The independent variable has been spatial skills training for experimental groups through tasks $B_2/_{bis}$ and $B_{3A}/_{bis}$. It influenced the dependent variable of the performances of experimental groups in intrinsic static and dynamic logical spatial tasks. Research design permitted the inferences needed to examine the hypothesis through experimental tasks which have been structured to evaluate intrinsic-static skills – the processing of shapes, or parts of shapes, through coding their spatial features and configuration of parts – and intrinsic-dynamic skills – the manipulation or transformation of shapes (Newcombe & Shipley, 2015; Hodgkiss, Gilligan, Tolmie, Thomas, & Farran, 2018). Practical activities for learners aged 9 to 11 years old have concerned spatial sequencing, spatial proportions, and association of numbers to geometric shapes; recognizing and isolating geometric shapes embedded in a contextual framework, hidden among distracting background information; linguistic categories and spatial relations (Uttal et al., 2013; Newcombe & Shipley, 2015) in comprehension, representation, and association tasks. The architecture of the research design has been structured within a quasi-experimental schema. Research procedure consisted then of two experimental phases (A and B), and a final evaluation phase. The experimental schema has been the following (Viganò, 1995):

[13] Numerical values have been attributed according to reached score in linking given labels to the right corresponding spaces in the original schema as follows: all labels as in the original schema, score 5; 2 inverted labels or blank spaces, score 4; 3 inverted labels or blank spaces, score 3; 4 inverted labels or blank spaces, score 2; 5 inverted labels or blank spaces, score 1; more than 5 errors, no score.

EG	O_1	X	O_2
CG	O_3		O_4

Teachers were open to collaborate to this research even if they were naïve to experimental hypotheses. The time course of the whole intervention has been divided in two times. The first session lasted about three hours divided into two days for each school. The second session lasted about one and half hour divided into two days for each school.

Results

Students in the two schools did not differ on the pretest, t (53) = 0.30815, p = .379588; scores in S_1 (M = 3, SS = 30) were closely comparable to those in S_2 (M = 2.9, SS = 40.71). In both schools, students reached *A* in the test A_1, which qualitative ranking has been assigned on the basis of alphabetical variables[14]. Test A_3 showed not statistically significant differences in errors (Table 2), t (53) = -0.1967, p = .422408 between training groups (M = 3.71, SS = 26.96) and control groups (M = 3.77, SS = 53.42) as in re-test A_5, t (60) = -0.41039, p = .34149, in which EG (M = 4.29, SS = 58.39) and CG (M = 4.42, SS = 33.55) did not differ, and in re-test A_{5bis}, t (53) = -0.7614, p = .224895 between EG (M = 3.59, SS = 38.52) and CG (M = 3.86, SS = 49.43). Comparing results of both test A_3 and re-test $A_5/_{bis}$ in training and control groups conditions (M = 0.48, SD = 1.93), not statistically significant differences emerged, t (5) = 1.90641, p = .11491.

Table 2
Errors in test A_3 and re-test $A_5/_{bis}$

errors (%)	test A_3	re-test A_5	re-test A_{5bis}
EG S_{1+2}	47.8	71.5	52.1
CG S_{1+2}	60.9	71.3	56.2
errors (x)	test A_3	re-test A_5	re-test A_{5bis}
EG S_1	2.8	3.7	3
CG S_1	4.1	4	3
EG S_2	2.8	4.7	3.5
CG S_2	3.9	4.4	4

In exercises $B_2/_{bis}$, percentage of failed patterns of training groups in S_1 (M = 53.5, SS = 264.5) and in S_2 (M = 82, SS = 288) was not statistically significant, t (2) = -1.71472, p = .114266. Anyway, delta percentage shows a variation of score in groups' performances in test A_3 and re-test $A_5/_{bis}$ (Table 3) and a decrease of failed patterns higher in S_1 (-35.4%) than in S_2 (-25.5%) in exercises $B_2/_{bis}$.

[14] According to the amount of shapes (forms) which have been recognized between the following ranges: 96-100%, position A; 91-95%, position B; 71-90%, position C; 51-70%, position D; 31-50%, position E; 01-30%, position F.

Table 3
Score in test A_3 and re-test A_5/bis and Δ percentage differences

score (%)	test A_3	re-test A_5	Δ	test A_3	re-test A_{5bis}	Δ
EG S_1	2.8	2.2	-21.4 %	2.8	2.7	-3.6 %
CG S_1	1.8	1.8	0	1.8	2.8	+55.6%
	test A_3	re-test A_5	Δ	test A_3	re-test A_{5bis}	Δ
EG S_2	2.9	1.2	-58.6%	2.9	2.4	-17.2%
CG S_2	2.7	1.5	-44.4 %	2.7	1.9	-29.6%
score (X)	test A_3	re-test A_5	re-test A_{5bis}			
EG S_{1+2}	2.9	1.7	2.5			
CG S_{1+2}	2.3	1.6	2.3			

Training and control groups in S_2 did not differ on the test B_4 and B_{4bis}, χ^2 (5, N = 34) = 1.081, p = .298472, while percentage of errors in S_1 were instead statistically significantly different, χ^2 (5, N = 29) = 5.162, p = .023086 (Table 4).

Table 4
Errors in test B_4 and test B_{4bis}

errors (%)	test B_4	test B_{4bis}
EG S_{1+2}	38.1	16.7
EG S_1	37	13.6
EG S_2	39	19.2
CG S_{1+2}	44.3	35.5
CG S_1	50.3	44.2
CG S_2	39	27.8

Eventual bias due to sample size difference in S_1 (EG 14 students, CG 15 students) have been considered in test B_4/bis, in which observed average score (Table 5) of training (M = 2.65, SS = 1.44) and control groups (M = 1.2, SS = 1.28) was not statistically significant, t (2) = 1.24222, p = .170028.

Table 5
Score in test B_4 and test B_{4bis}

average score	test B_4	test B_{4bis}
EG S_{1+2}	1.7	3.5
EG S_1	1.8	3.5
EG S_2	1.7	3.4
CG S_{1+2}	1	2.4
CG S_1	0.4	2
CG S_2	1.6	2.8

Percentage of differences between students' answers to an interview asking if "it is useful or not to have the aid of images (intended as schemas) during the learning process" has been calculated (Figure 1). The 96.50 % of students in school Cimarosa answered *yes* (3.50 % *no*), while the 35.50 % of students in school Mallardo answered *yes* (23.50 % *no*, 41 % *maybe*).

Fig. 1 Motivation to spatial learning of schools Cimarosa and Mallardo

Discussion

The pretest has been analyzed in the whole sample (both training and control groups). Not statistically significant differences emerged between the observed averages of the two schools Cimarosa and Mallardo. In test A_1, which involved only perceptual skills, the best score has been easily reached by all students. Test A_3 implied instead perceptual and conceptual skills. Students performing test A_3 reached less times the best score. In test A_3 and re-test $A_5/_{bis}$, students' errors have allowed to calculate expertise of training and control groups. Not statistically significant differences have emerged. Nevertheless, comparing the average of errors in test A_3 and re-test A_5, results show a variation of groups' performances, which have been separately analyzed in the two schools. School Cimarosa shows less errors in average (Figure 2).

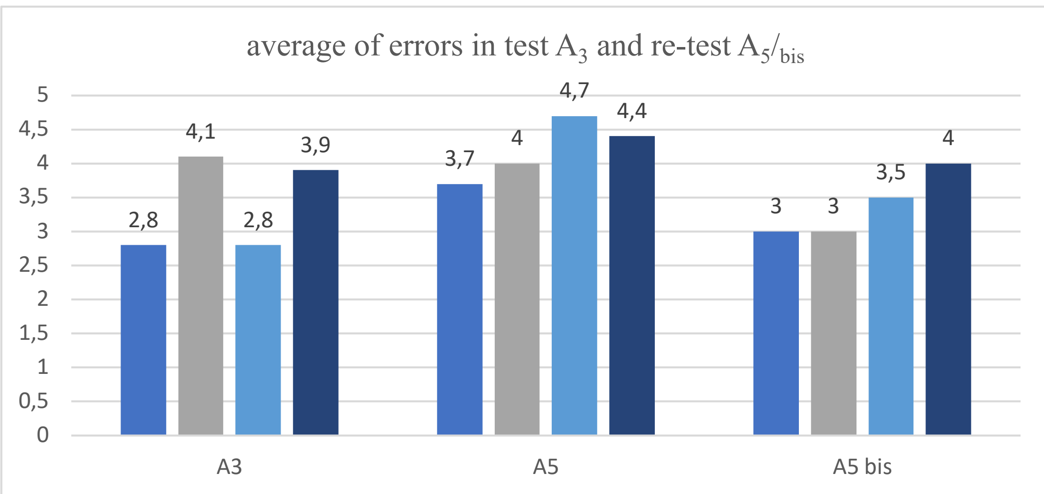

Fig. 2 Average of errors of students of schools Cimarosa and Mallardo

To see if reducing the complexity of the task may influence groups' performances, re-test A_5 has been repeated as re-test A_{5bis}, which confirmed a difference between the levels of expertise of training and control groups. Learners performed better in re-test A_{5bis}. The gap between test A_3 and re-test A_{5bis} results became less relevant. The *delta* (Δ) percentage showed a minor decrease of score in school Cimarosa than in school Mallardo (Figure 3).

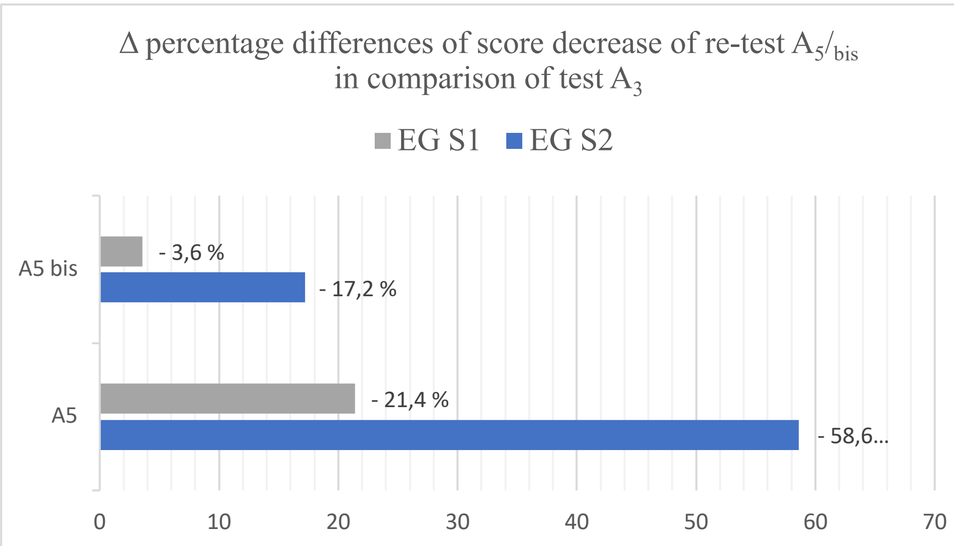

Fig. 3 Δ percentage differences of decrease of score comparing test A_3 and re-test $A_5/_{bis}$

Differences between training and control groups then emerged in test A_3, in favor of training group in both schools. Comparing test A_3 and re-test A_5 results, levels of expertise were decreasing. It could be an indicator of complexity of re-test A_5, which task has been repeated in the simpler re-test A_{5bis}, consequently showing higher results. Re-test A_{5bis} confirmed a difference between training and control groups performances in favor of training groups. School Cimarosa performed better than school Mallardo in both re-tests; anyway, less complex was the task, narrower were the performances of training groups in schools Cimarosa and Mallardo. Training and control groups' score had a percentage of improvement in both schools comparing re-test A_{5bis} to re-test A_5 and re-test $A_5/_{bis}$ to test A_3. Training group of Cimarosa performed better than Mallardo from re-test A_5 to re-test A_{5bis}. Students of school Cimarosa managed a complex task more easily than students of school Mallardo.

A research interpretation could refer to the surrounding context of the two schools. School Cimarosa is a sociocultural and economic advantaged context, while school Mallardo is located in a disadvantaged Municipality. In the educational background of the socioeconomic status (SES) students of school Cimarosa, spatial education is relevant. Learners are encouraged by teachers' and parents' scaffolding to use spatial learning, as shown by students' answers to the research interview. A scaffolding context sustains learners in adaptive situations and offers guidance in complex learning situation. According to the original Adaptive Learning Environments Model (ALEM) (Wang, 1984), learning should be facilitated in different cognitive, cultural, and socioeconomic backgrounds by encouraging self-efficacy enhancement over academic skills. SES backgrounds seemed to be more scaffolding in promoting self-efficacy skills. Quantitative and qualitative results showed indeed that SES learners statistically performed better.

In B phase, spatial skills training for experimental groups has been repeated two times with a different learning content (a curricular formal text on Roman history in exercise B_2 and an extra-curricular informal story on a Family in exercise $B_{2\ bis}$). Not statistically significant differences have emerged between the performances of training and control groups in both schools, but *delta* (Δ) showed that the percentage of failed patterns from exercise B_2 to exercise B_{2bis} decreased in school Cimarosa more than in school Mallardo (Figure 4).

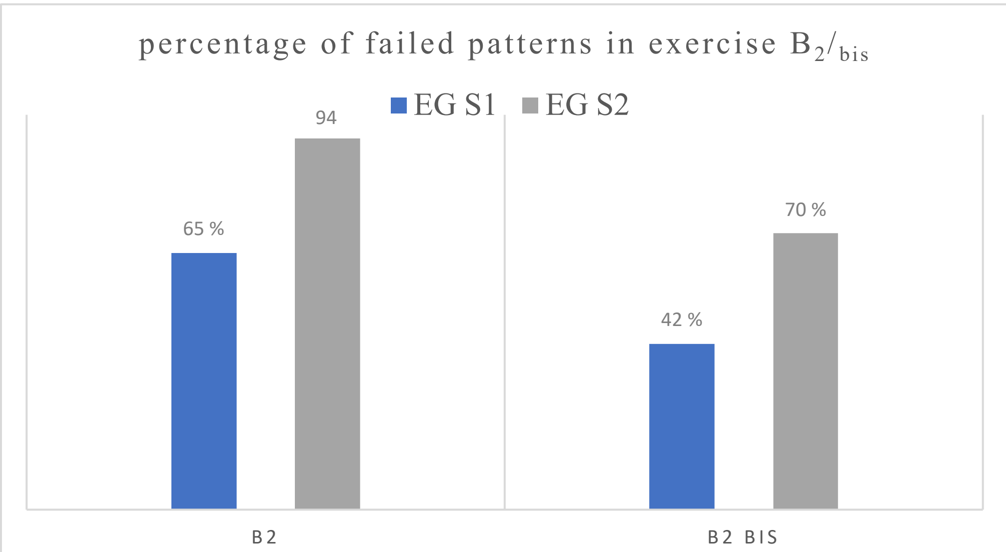

Fig. 4 Percentage of failed patterns in exercises $B_2/_{bis}$

From exercise B_2 to exercise $B_{2\ bis}$ emerged a raise of percentage of success (in terms of decrease of failed patterns) probably due to the repetition of the task changing the learning content. In exercise B_2, a curricular formal text on Roman history, learners had to cope with a double learning effort–understanding new content's concepts and spatially organizing it. In easier exercise B_{2bis}, an extra-curricular informal story on Family, learners performed better in relation to the learning content, which could have previously heard.

Comparison of errors in test $B_4/_{bis}$ between experimental and control groups has allowed to evaluate how the percentage of errors decreases. Results show statistically significantly differences only in the performances of school Cimarosa, while no statistically significant differences emerged in the performances of school Mallardo. In test $B_4/_{bis}$ training group performs better than control group in both schools.

Spatial skills training (independent variable) showed a positive effect on the performances of experimental groups in experimental intrinsic static and dynamic logical spatial tasks (dependent variable). Research hypothesis has been confirmed by test $B_4/_{bis}$ results, in which spatially trained experimental groups performed better than control groups. Statistically significantly differences have emerged only in the performances of experimental and control groups of the advantaged sociocultural and educational background of school Cimarosa. School Cimarosa's students showed higher motivation to learn using spatial skills than school Mallardo probably because contextual scaffolding has encouraged spatial education and the enhancement of spatial skills. Parents' and teachers' guidance in complex situations have sustained Cimarosa's students, since they show better self-efficacy skills. All these aspects may have affected their own learning performance, which resulted significantly higher than school Mallardo's one.

Conclusion

Spatial skills training has been considered of significative importance in primary education, especially to develop science achievement. Despite spatial skills can be trained and may represent a learning facilitator, the field of language comprehension and logical reasoning applied to the spatial representation and to the recognition of spatial relations is still undeveloped.

In this research, experimental hypothesis suggested that spatial skills training in different environmental contexts can play as a variable booster for learners aged 9 to 11 years old to improve their perceptual/abstract and implicit/explicit processing. Learners of different sociocultural and economic backgrounds have been supported by spatial skills training (independent variable) to enhance their performances in spatial tasks (dependent variable) involving basic logical processing and comprehension, representation, and association of linguistic categories and spatial relations.

Results showed that, after spatial skills training, learners aged 9 to 11 years old better recognized the possible relations between perceptual/abstract and implicit/explicit processing when performing in intrinsic static and dynamic logically based spatial tasks.

Data availability statement

All data generated or analyzed during this study are included in this published article. The study involves human participants. Students and their families were informed of the experimental tasks and gave their consent.

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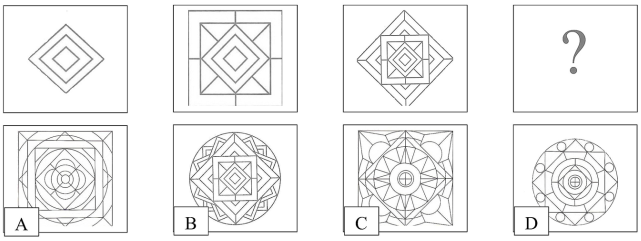
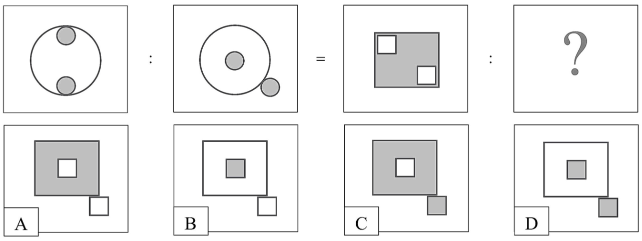
Appendix A pre-test 0_1

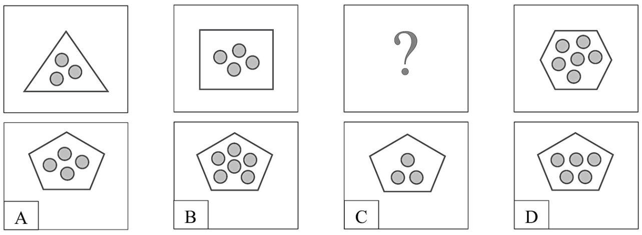
1. Which figure is missing from the sequence of three images?



2. Which figure completes the proportion between the images?



3. Which figure should be added to the series of images?

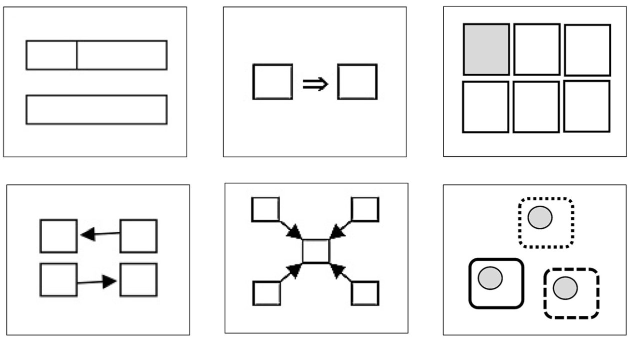


Appendix B test A_1

The drawing contains rectangles, squares, ovals, rounds and arrows. Can you find them? Coloring is easier! I found ... forms.

Appendix C test A_3

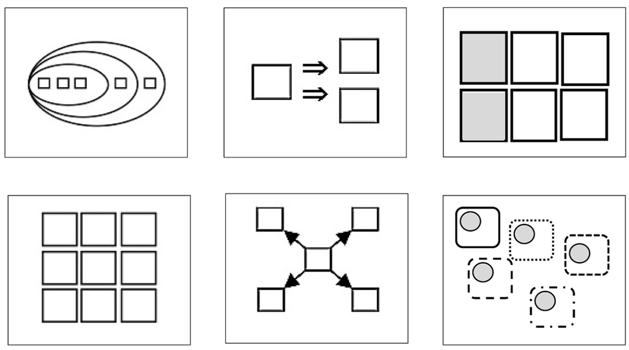
Link each figure with a single sentence:



- I pushed the obstacle so much that it dropped
- Sun, sea, heat, ice creams: summer is coming!
- Both me and both Maria and Andrea play tennis
- Sometimes I feel a little good and a little mean
- As far as I'm concerned, I don't want to participate
- Anna is more beautiful than me, but I'm better

Appendix D re-test A_5

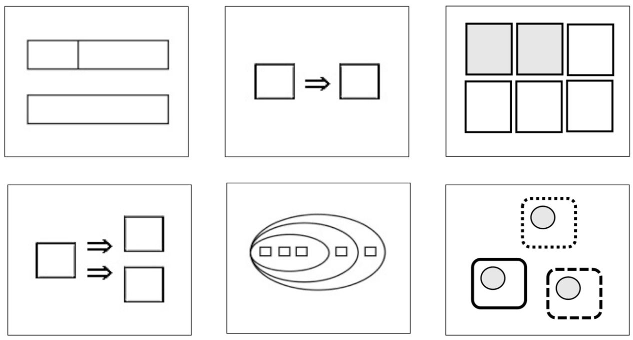
Link each figure with a single sentence:



- Each Region of Italy has a recipe for cooking pasta
- Not even Maria (and neither have I) were invited to the party
- Taking cold brings fever, cough, cold and headache
- I bought a cake to offer it to friends and to eat a slice
- Even if we are different, we are all classmates
- I was playing with Anna and Mario, then Andrea came, and finally Elena arrived

Appendix E test A_{5bis}

Link each figure with a single sentence:



- I ate so much that I felt sick
- Ball, stadium, players, referee: so it's football!
- Both cream, yogurt and ice cream contain milk
- Among the desserts I prefer the babà and the sfogliatella
- Only I can't swim
- Dad drives better than Mum, but Mum is more cautious

Appendix F

Example B_1

Roman society was divided into **three** social **classes**:

- **Patricians**: the aristocratic ruling class of landowners who sat in the Senate. Their name derives from the Latin word *patres* which means fathers, senators.
- **Plebeians**: peasants, small traders, artisans. They were poor and unemployed. They lived apart from the patricians with whom they could not marry. They came from families who came to Rome after its foundation.
- **Slaves**: people without any rights who worked in fields, in mines and at service of patricians and plebeians (not having slaves was a sign of poverty). They were sold on a stage in the markets and in the forum (central square) with a sign at the neck to indicate where they came from and what they could do.

Furthermore, there were:

- **Clientes**: rich people who have fallen into ruin and become plebeians. In exchange for protection and favors, they offered to aristocrats' electoral services and votes.
- **Liberti**: slaves who obtained freedom as a reward for services and loyalty to their master.

Example B_{1bis}

The **Esposito family** consists of *three members*:

- **Mum**: Mrs. Esposito is a very kind woman. She is 35 years old, brown, has long hair on her shoulders. She always prepares the afternoon snack for her son's friends.
- **Dad**: Mr. Esposito is a big man. He is 38 years old, with short hair, a beard and a mustache. He really likes playing football. He plays every day with his son, to whom he has transferred his passion for this game.
- **Son**: a smart kid but ... he doesn't like school so much. He prefers to play football, a passion he has received from Dad and that unites them: they both like the game of football.

Moreover, there is:

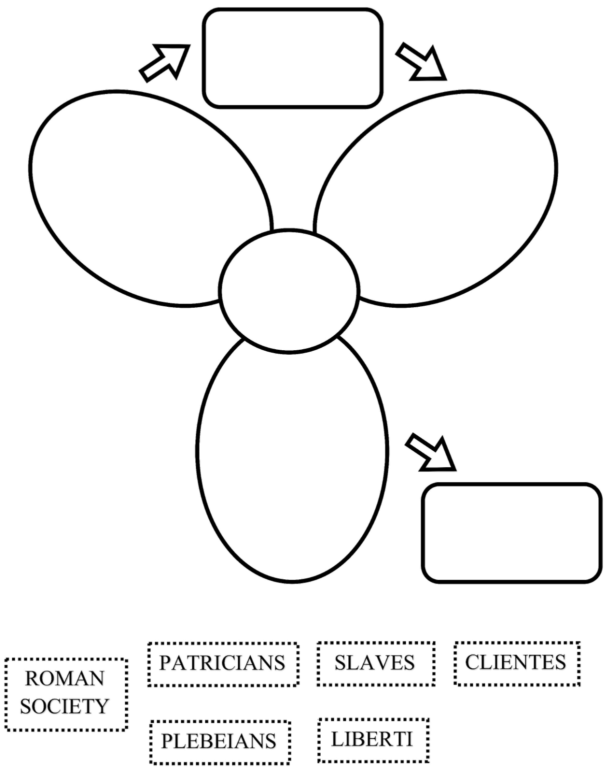
- **Aunt**: is the sister of Mum. They are always very close and share every situation. But Mum is a little older than the Aunt, so often Mum influences the Aunt in her choices.

Together Dad and son play at:

Football: Dad was not very good and always lost!

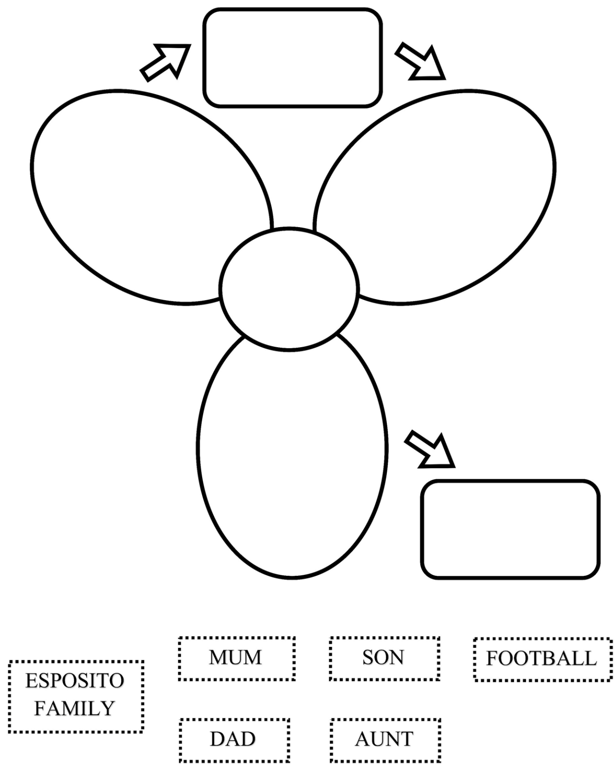
Appendix G exercise B_2 (only for experimental groups)
Complete a *chain* and *focus* shape from the *Roman society* text

Complete the underlying shape by cutting out the labels and gluing them where it looks best.



Appendix H exercise B_{2bis} (only for experimental groups)
Complete a *chain* and *focus* shape from the *Family* text

Complete the underlying shape by cutting out the labels and gluing them where it looks best.



Appendix I

Exercise B_{3A} (only for experimental groups)

In 509 BC the Roman patricians abolished the monarchy and proclaimed the **Republic**, formed by:

- **Consuls**: they were two, *above* all, at the head of the army and the government. They remained in office for a year. They were elected by *comizi centuriati*.
- ***Comizi centuriati***: assemblies *in the midst* of which there were both patricians and plebeians. They elected *from below* consuls and magistrates. At first, plebeians could vote but could not be elected; their representatives were therefore *outside* the Senate. Later **Tribunes of the plebs** could be elected, *next to* the patricians, by **Assembly of the plebs**–so as to stay *inside* the Senate to defend their rights.
- **Senate**: was *behind* consuls to advise them and approved laws.
- **Magistrates**: collaborated with consuls. They were divided into four aligned *sub*-categories. Among them were:

- **Praetors** to administer justice
- **Quaestors** to collect taxes and govern public finances
- **Censors** to register citizens and their assets
- **Constructors** to control public works

Exercise B_{3B}

In 509 BC the Roman patricians abolished the monarchy and proclaimed the **Republic**, formed by:

- **Consuls**: they were two, at the head of the army and the government. They remained in office for a year. They were elected by *comizi centuriati*.
- ***Comizi centuriati***: assemblies formed by patricians and plebeians. They elected consuls and magistrates. At first, plebeians could vote but could not be elected. Later **Tribunes of the plebs** could be elected by **Assembly of the plebs** to defend their rights.
- **Senate**: advised consuls and approved laws.
- **Magistrates**: collaborated with consuls and were divided into:

- **Praetors** to administer justice
- **Quaestors** to collect taxes and govern public finances
- **Censors** to register citizens and their assets
- **Constructors** to control public works

Appendix L

Exercise B_{3Abis} (only for experimental groups)

Esposito family is now composed of *four members*:

- **Mum**: Mrs. Esposito loves hobbies very much: she likes **reading**, **sewing**, **knitting** and **cooking**. Spends a lot of time *close to* Dad and little sister.
- **Dad**: Mr. Esposito, as we know, loves a lot to play **football**. This activity is *at the center of* the thoughts of Dad and son. He also spends a lot of time talking to Mum.
- **Son**: the son grew up. Not only he plays football, but his passion for **football** has become so strong that he has put together a team with friends. He called it Esposito Team. He would like to play with his little sister, but from her, from *the bottom of* his cradle, he receives above all great **headaches**.
- **Little sister**: she was born recently. He always cries and shakes in the cradle. Drinks milk. His screams are so sharp that they always give the brother a **headache**. But she is all oriented *towards* her brother and she is always smiling at him.

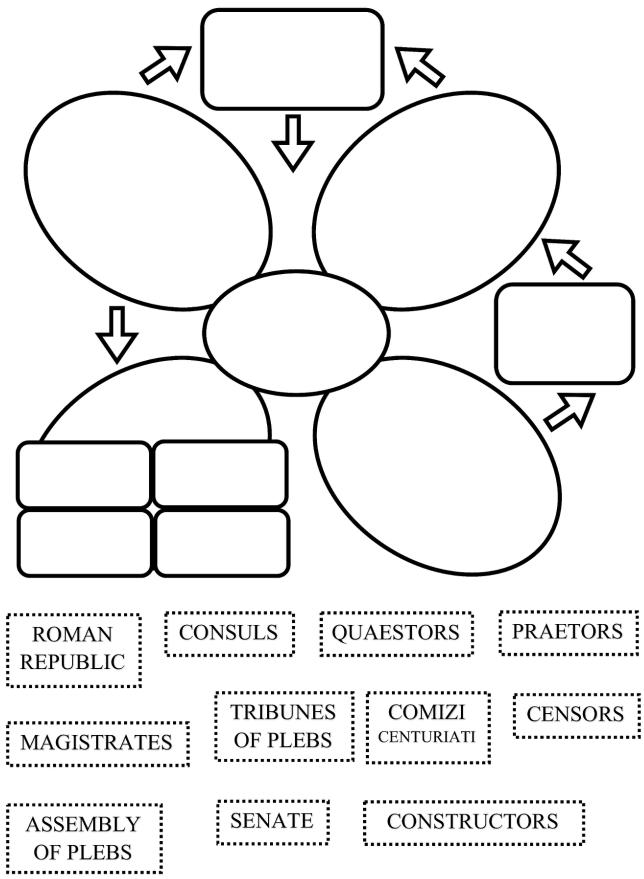
Exercise B_{3Bbis}

Esposito family is now composed of *four members*:

- **Mum**: Mrs. Esposito loves hobbies very much: she likes **reading**, **sewing**, **knitting** and **cooking**.
- **Dad**: Mr. Esposito, as we know, loves a lot to play **football**. He also spends a lot of time talking to Mum.
- **Son**: the son grew up. Not only he plays football, but his passion for **football** has become so strong that he has put together a team with friends. He called it Esposito Team. He would like to play with his little sister, but from her, he receives above all great **headaches**.
- **Little sister**: she was born recently. He always cries and shakes in the cradle. Drinks milk. His screams are so sharp that they always give the brother a **headache**.

Appendix M test B_4

Complete the underlying shape by cutting out the labels and gluing them where it looks best.



Appendix N test B_{4bis}

Complete the underlying shape by cutting out the labels and gluing them where it looks best.