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Introducing a Precursor Model of Inheritance to Young Children

Marida Ergazaki*, Eftychia Valanidou,
Maria-Christina Kasimati and Mara Kalantzi
Department of Educational Sciences & Early Childhood Education, University of Patras, Rio-Patras, Greece

This paper reports on a mixed-model case study of designing and implementing a constructivist teaching intervention about reproduction and physical family resemblance for young children. The objective of the study was to explore whether the ways that preschoolers reason about the resemblance between offspring and parents can be improved with a teaching intervention that introduces a rudimentary idea of genes through reproduction. The participants were 60 preschoolers (age 5–5.5 years) from public kindergartens of Patras. The qualitative analysis of their pre- and post semi-structured interviews showed a remarkable improvement in their reasoning, which was found to be statistically significant as well. After the three-part teaching intervention, children appeared to recognize the biological contribution of both parents to a child's creation. Moreover, most of them appeared able to attribute a child's species and body traits to the parental genes passed to the child through reproduction and not to the parents' or child's intention.

Keywords: *Early childhood education; Biology education; Teaching inheritance to preschoolers; Destabilizing preschoolers' intentional reasoning*

Introduction

Background of the Study

Cognitive and educational research in early childhood is significantly concerned with how young children start constructing their knowledge about the biological world (Inagaki & Hatano, 2002), and how they may be supported with appropriately designed teaching interventions (Ergazaki, Saltapida, & Zogza, 2010). It has been suggested (Keil, 1994; Wellman & Gelman, 1992) and also challenged (Carey,

*Corresponding author. Department of Educational Sciences & Early Childhood Education, University of Patras, 26500 Rio-Patras, Greece. Email: ergazaki@upatras.gr

1995) that preschoolers hold naive theories in biological contexts such as growth, illness transmission, and inheritance. Despite the contradictory conclusions about children's initial understanding of inheritance (Ergazaki, Alexaki, Papadopoulou, & Kalpakiori, 2014; Solomon, Johnson, Zaitchick, & Carey, 1996; Springer, 1992), one can find some reports of interesting teaching attempts in this context (Schroeder, McKeough, Graham, Stock, & Palmer, 2007; Solomon & Johnson, 2000; Springer, 1995; Williams & Affleck, 1999).

Drawing upon Springer (1995), Williams and Affleck (1999) designed a teaching intervention about inheritance for 4- and 7-year-old children, based on the essential facts of a baby's life inside the mother's body. Although, according to Springer, familiarizing children with these facts could improve their reasoning about inheritance, this experimental study did not show a significant improvement.

Solomon and Johnson (2000) designed a short, 20-minute training session for 5–6-year-olds, drawing upon Springer (1995) as well. This time children were provided with the basic facts of a baby's life inside the mother's body along with a rudimentary idea of genes, meant to serve as a 'conceptual placeholder' or 'conceptual peg'. In other words, Solomon and Johnson used a very simplified idea of genes to help children 'hold in place'/organize these facts. Children got familiar with the idea that the 'rabbit-genes', for instance, are (a) transmitted from the 'rabbit-mother' to the child when the latter is growing inside her body and (b) make the child a little rabbit too. According to their findings, children who participated in the intervention were more likely to make adult-like judgments in inheritance-tasks than those who did not.

More recently, Schroeder et al. (2007) designed an extended teaching intervention of 15, 20-minute sessions for 4–5-year-olds. Children were introduced to the idea of both parents' contribution to a baby's creation through 'egg' and 'sperm'. The results of this experimental study showed that biological inheritance may be discussed with preschoolers in combination with reproduction. Schroeder et al. (2007)—unlike Solomon and Johnson (2000)—avoided the idea of genes as a 'conceptual peg', being skeptical about its developmental appropriateness. Nevertheless, appealing to young children's 'psychological essentialism' about the natural world (Gelman & Wellman, 1991), one might argue that a rudimentary idea of genes *may* be consistent with children's reasoning.

According to the essentialist assumption, members of biological (or even social) categories (e.g. members of an animal species or gender) have an internal, not necessarily known, unchanging property. This 'constitutive essence' or 'innate potential' is unique and determines their identity and their external features (Gelman & Wellman, 1991; Taylor, Rhodes, & Gelman, 2009). It seems plausible that a rudimentary idea of genes might describe a little bit better this 'essence' of living entities children intuitively assume. In other words, it might provide children with a slightly *less* abstract representation of what they already seem to consider as crucial for the identity and the external features of living organisms.

Even though inheritance is hard for young children, one should not overlook that (a) relevant studies such as those of Solomon and Johnson (2000) and Schroeder et al. (2007) produced promising results, and (b) children have also been reported with significant potential in other demanding contexts such as, for instance, ecological relationships (Ergazaki & Andriotou, 2010), germs (Ergazaki et al., 2010), friction (Ravanis, Koliopoulos, & Boilevin, 2008), or energy (Koliopoulos & Argyropoulou, 2011).

In fact, research has shown that young children tend to be surprisingly ready to engage in demanding thought processes when provided with appropriate educational settings. According to Donaldson (1978, as cited in Woodhead & Faulkner, 2000), young children can show rather sophisticated competencies in settings that are close to their normal, everyday experience. Forman (2010) argues that analyzing ordinary moments of 2–3-year-olds' play can reveal a legitimate form of scientific thinking manifested through pattern, structure or cause seeking. Metz (2004) argues that when given the chance to reflect on their own investigations, fourth or even second grade students can reach an essential understanding of uncertainty as an inherent feature of scientific inquiry. Children's readiness to *start* recognizing the complex relationship between the natural world and our knowledge about it is actually remarkable.

So, willing to invest on children's early competencies, we found it interesting to explore whether preschoolers might be able to respond to a teaching intervention about family resemblance, which combines and extends the ideas of both Schroeder et al. (2007) and Solomon and Johnson (2000). In fact, it is based (a) on the notion of *both* parents' contribution to the creation of a child through 'sperm' and 'egg', which has already been used by Schroeder and colleagues, and (b) on a very simplified notion of genes, which is however more advanced than the one already used by Solomon and Johnson. Genes are introduced as very 'tiny things', which are located inside dad's 'sperm' and mum's 'egg', not just inside mum's body like Solomon and Johnson suggested; and since 'sperm' and 'egg' are united to create a child, dad's and mum's genes end up inside the child and cause its physical resemblance with the parents.

Research Questions

Thus, the research question of the study is: 'How do young children reason about reproduction and physical resemblance between parents and offspring, before and after the teaching intervention?' More specifically:

(1) How do young children reason about reproduction, before and after the teaching intervention?
   - Do they understand the contribution of both parents and how?

(2) How do young children reason about the 'parents–offspring' species resemblance, before and after the teaching intervention?
   - Do they recognize the 'parents–offspring' species resemblance and how do they explain it?
   - Do they realize that the wish/intention of the parents has nothing to do with the species of their offspring and how do they explain it?

(3) How do young children reason about the 'parents–offspring' resemblance in body traits shared by both parents, before and after the teaching intervention?

- Do they recognize the 'parents–offspring' body traits resemblance and how do they explain it?
- Do they realize that the wish/intention of the parents has nothing to do with the body traits of their offspring and how do they explain it?

It is worth mentioning that exploring the research questions presented above can give rise to implications about whether children at this age have possibly the potential to reason about inheritance or the abstractness of the latter is prohibitive for them. Adding to the more optimistic post-Piagetian view about young children's domain-specific, reasoning potential *does* lie in our rationale. So, the relevant implications of our findings are highlighted in the discussion.

Methods

Overview of the Study

This is a mixed-model case study that includes (a) tracing 60 preschoolers' intuitive reasoning about reproduction and physical family resemblance with individual, semi-structured pre-interviews, (b) designing a teaching intervention after considering the pre-interviews and the already tested teaching interventions, (c) implementing the teaching intervention with 12 groups of five children, and (d) exploring its learning impact by analyzing children's pre- and post-interviews qualitatively and quantitatively.

Participants

The participants were 60 preschoolers of three public kindergartens in areas of Patras with medium socioeconomic status, who were selected due to their teachers' agreement to facilitate our research. At the beginning of the study, the children (age: 5–5.5 years; gender: 33 girls, 27 boys; nationality: 56 Greeks, 4 Albanians) were already familiar with educational interactions since they had been attending kindergarten for several months. Nevertheless, according to their teachers they had never been exposed to *formal* educational activities about reproduction and inheritance in class until then. The parents were informed about the study before its start, in order to confirm that they did not have any objections to their children's participation.

Pre- and Post-interviews

The second and third authors (those who implemented the intervention) conducted individual, semi-structured pre- and post-interviews with the children. The interviews were taken in quiet places of children's schools and their average duration was 30 minutes. This is a very common technique for collecting qualitative data from preschoolers; it allows researchers to have a one-to-one interaction with children who have the chance to respond without being influenced by classmates, but on the other hand it requires attention for not causing them any psychological damage (Brooker, 2005).

After having tested our protocol with other children of similar profile and discussed possible 'follow-up' probes, we started the pre-interviews' phase with our informants. In order to reduce the risk of putting them under undesired psychological stress, we first gave them the chance to meet the two authors who would take the interviews and perform the intervention, get familiar with them and give their own assent for participating. One week after completing the teaching intervention these two authors also took the post-interviews, following the same protocol. In order to be presented here, children's responses were translated from Greek into English. The accuracy of this English version was ensured through careful checking by the two interviewers who were engaged in reaching consensus.

The interview protocol was structured in three parts, concerning (i) reproduction (task 1), (ii) 'parents–offspring' species resemblance (tasks 2.1–2.2), and (iii) 'parents–offspring' body traits resemblance (tasks 3.1–3.2). Apart from task 1, the protocol-tasks were modified versions of those originally used in studies of developmental psychology concerned with aspects of children's reasoning that concern us as well. Thus, their reliability and content validity have already been tested.

Interview Protocol: Part I—'Reproduction'

Children were first told a story about a couple of bears who loved each other and wanted to have a baby but did not know what they needed to do. Then they were required to help them by making their own suggestions.

Interview Protocol: Part II—'Parents–Offspring Species Resemblance'

This part includes the 'family making'-task (task 2.1) and the 'parents' intention and baby's species'-task (task 2.2) which is a species-oriented version of the 'wish-fulfillment task' (Schroeder et al., 2007; Weissman & Kalish, 1999). In task 2.1, children were presented with three cards depicting couples of adult animals (foxes, lions and penguins) and five cards depicting baby animals (fox, lion, penguin, mouse and rabbit). They were required to 'make families' and then justify them. When their responses were not clear enough, follow-up probes were used for clarifications. In task 2.2, children were required to think what would happen if parents of one species wished to have a baby of another. The question was repeated with one or two of the couples, when needed. For details, see Appendix 1.

Interview Protocol: Part III—'Parents–Offspring Body Traits Resemblance'

Children were engaged in modified versions of two well-known tasks: (a) the 'functionality task' (Springer, 1995; Springer & Keil, 1989) and (b) the 'wish-fulfillment task' (Schroeder et al., 2007; Weissman & Kalish, 1999). In task 3.1, they were required to make justified predictions about whether a child would have specific traits of his/her parents that were peculiar/unusual within the species or it would have the usual traits that all others have. In task 3.2, children were required to make justified predictions about whether a child would have specific inborn physical traits of his/her parents or the child would have the traits that the parents deeply wished for him/her to have. We used the same four traits in both tasks and counterbalanced them across children. For details, see Appendix 1.

Teaching Intervention

Children's responses in the pre-interviews revealed a background upon which one could attempt to build a better understanding of inheritance. More specifically, (a) a few participants *did* refer to the contribution of both parents to a child's creation, (b) most seemed to recognize the 'parents–offspring' species resemblance, and (c) most seemed to recognize the 'parents–offspring' body traits resemblance as well.

Being consistent with the theoretical framework of constructivism (Driver, Asoko, Leach, Scott, & Mortimer, 1994), we decided to introduce a rudimentary idea of genes and possibly give children the opportunity to explain better the family resemblance they already appeared to recognize. The teaching intervention we designed aims at facilitating children in developing 'pre-biological' reasoning about the 'parents–offspring' resemblance by appealing to a rudimentary idea of genes and gene transmission through the process of reproduction. Children's young age and the importance of promoting an active learners' attitude were taken into account, as shown by the type of the activities that make up our three-part teaching intervention (Table 1).

In the first part of the teaching intervention ('Reproduction & mechanism of the "parents–offspring" species-resemblance': six activities), we are concerned with the following: (a) how a child is born, (b) how the 'parents–offspring' species resemblance derives, and (c) why the intention of the parents cannot influence the child's species. In the second part ('Mechanism of "parents–offspring" resemblance in body traits shared by both parents': two activities), we are concerned with (a) how offspring end up to resemble their parents in body traits shared by both of them and (b) why the wish or intention of the parents cannot influence the body traits of their offspring. Finally, in the third part ('Consolidation with multiple-case scenarios of adoption & wish': two activities), we provide a context for consolidating the ideas that have already been introduced in the first two parts (for details, see Appendix 2). The teaching intervention was implemented to 12 groups of 5 children at a similar level by the second and third authors. The implementation took three consecutive schooldays for each group and 1–1.5 hours per day.

Overview of the Analytic Procedure

The tape-recorded pre- and post-interviews were transcribed and prepared for coding with 'NVivo', a software for qualitative data analysis. Then we created a series of data-driven categories by reading children's responses to each task and coding their claims

Table 1. Overview of the teaching intervention

Title of activity		Type of activity	Target idea of activity
1.1	'Make the animal families'	Guided card-sorting and discussion	'X-gives-birth-to-X'
1.2	'How the rabbit-couple had their baby-rabbit'	Card-based story with active participation (Qs and As)	How babies are born: mum's egg and dad's sperm give rise to a baby
1.3	'Why the rabbit-couple can only have baby-rabbits and not … puppies?'	Brainstorming	Understanding that they do not have a good explanation about why X gives birth to X
1.4	'The rabbit-couple can only have baby-rabbits because of the rabbit-genes they have in their egg & sperm'	Card-based story with ctive participation (Qs and As)	Why X gives birth to X: 'species-genes' within parents' egg and sperm
1.5	'Draw the species-genes in mum's egg & dad's sperm that will give rise to their baby'	Guided drawing and discussion	Why X gives birth to X: 'species-genes' within parents' egg and sperm
1.6	'Can the rabbit-couple have a baby-tiger, baby-frog or baby-mouse if they wish for it very much?'	Role play and discussion	Why X cannot give birth to Y: parental 'species-genes' vs. parental intention
2.1	'How I came to the world with blue eyes, while my parents wished that I came with brown ones'	Card-based story with active participation (Qs and As)	Parental 'trait-genes' vs. parental intention
2.2	'Guess the traits of the wishing-parents' child'	Floor-game with justified predictions	Parental 'trait-genes' vs. parental intention
3.1	'Parents of X species adopt a child of Y species'	Puppet show with active participation (Qs and As)	Parental 'species-genes' vs. offspring's social interaction and wish
3.2	'Parents with trait A adopt a child with trait B'	Card-based story with active participation (Qs and As)	Parental 'trait-genes' vs. offspring's social interaction and wish

and justifications. So, our coding scheme derived through 'open coding' (Gibbs, 2009) and included categories of children's 'claims & justifications' about

(a) the parental contribution in the creation of a child (e.g. 'Mum_tummy', 'Mum & dad_tummy & loving care', 'Mum & dad_egg & sperm'),
(b) which animals can be a family (e.g. 'Correct family_X-gives-birth-to-X' or 'Correct family_species-genes'),
(c) whether parents' intention/wish can affect a child's species (e.g. 'Wish YES_God', 'Wish NO_parents'-child resemblance'),
(d) whether a child would have peculiar parental body traits (e.g. 'Parental body-trait YES_born by them', 'Parental body-trait NO_bad trait'), and
(e) whether parents' intention/wish can affect a child's body traits (e.g. 'Wish NO_trait-genes', 'Wish YES_power of the wish').

We gave each category a two-part name. The first indicates children's claim, while the second indicates children's justification. For instance, the code 'Wish NO_trait-genes' was used for the responses according to which the parental wish *cannot* affect the offspring's body traits (see code's first part) *because* these are determined by the trait-genes it gets from them (see code's second part).

The coding was performed independently by the first author and two of the three co-authors and the inter-rater reliability was satisfactory (Cohen's κ: .90). The categories that emerged are thoroughly discussed in the results section. The statistical significance of 'before & after' changes for data organized in categories can be tested with McNemar's test (Salkind, 2004). So, we used this test to examine whether children's shift to the 'desired' or to the 'target' categories from pre- to post-interviews was statistically significant or not.

Results

Results about Research Question I

In the pre-interviews, almost half of the children did not recognize the contribution of both parents to a child's creation: 22 referred only to the mother, leaving the father completely out of focus (see 'Mother_bio contribution' in Table 2), while the remaining 7 did not provide any response (see 'Don't Know' in Table 2).

Focusing on the former, it is worth noticing the following:

(a) Children appealed to parts and products of the mother's body such as her 'tummy', 'breast' or 'egg', in order to explain how a baby can be created (16/22). In children's own words:

- *'The bears have to wait for a long time and when the mum's tummy will be big, they will have a baby … it will come out of her tummy' (there is no idea about how the baby gets into mum's tummy).*
- *'She will give birth to the baby-bear from her breast … She will drink a lot of milk and her breast will be big and the baby will come out of it' (there is no idea about how the baby gets into mum's breast).*
- *'Mum will have to sit in their nest and make an egg. She must wait … after some time if she stands up, she will see the egg that came out of her butt … then the baby-bear will come out' (there is no idea about how the egg is produced).*

Table 2. Children's claims/explanations about parents' contribution to reproduction

	Mother_bio contribution	Both parents_bio contribution	Both parents_M bio & F psycho	Don't Know
Pre-interviews	22/60 (36.7%)	9/60 (15%)	22/60 (36.7%)	7/60 (11.7%)
Post-interviews	0/60 (0%)	60/60 (100%)	0/60 (0%)	0/60 (0%)

Note: 'M' and 'F' stand for 'Mother' and 'Father'; 'bio' and 'psycho' for 'biological' and 'psychological' contribution.

(b) Children involved another entity like 'God', 'plant seed', 'food' or 'doctor' in their explanations (6/22):

- *'They should go and make a wish to God … tell him that they want a baby-bear … God will do it. He will bring it in mum's tummy'.*
- *'She will take a seed from a flower … she will put it in her tummy … the baby will grow and come out from the tummy'.*
- *'Mum must eat a lot … bananas, pears … her tummy will get big and the baby will grow from the food and then she will go to the hospital and they will take the baby out of her tummy'.*
- *'Mum gets pregnant … then they go to the doctor and he takes the baby out of her tummy' (no idea about how the baby gets into mum's tummy).*

Almost the other half of the children (31/60) *did* consider *both* parents when trying to explain in their pre-interviews how a baby is born (Table 2), but only 9 of them seemed to recognize the father's biological contribution (see 'Both parents_bio contribution'):

- *'If the dad-bear and mum-bear love each other very much and want to have a child, he will give her a little seed that he has … he will put his seed in her tummy and it will grow and make a baby bear and the doctor of animals will get it out mum's tummy'.*
- *'They must kiss each other … a little sperm will get into mum's tummy from the man … it will go to the egg … mum has something like an egg in her tummy and the sperm goes there and they have a baby. They go to the hospital and the doctor gets the baby out of mum's tummy'.*

The paternal contribution was understood only as a psychological or social supplement to the mum's 'tummy-contribution' by the remaining 22/60 children (see 'Both parents_M bio & F psycho contribution'). The father's role was considered to be 'loving mum', 'taking care of her', 'marrying her', 'helping deliver the baby' and 'asking God for a baby':

- *'If he loves her very much, her tummy will get big and they will have a baby-bear … he gives her his love and the baby grows in her tummy'.*
- *'Mum's tummy will get fat and the dad will take her to bed to have some sleep and then he wakes her up and she takes her to the hospital and they have their baby'.*
- *'He must marry her. He must take her to the church to get married. Then she will have a baby in her tummy and the doctor will take it out'.*
- *'Mum will have the baby in her tummy and he will take a pair of scissors and cut the tummy to take the baby out'.*
- *'Dad must ask God to give them a baby. If he asks, God will send a baby in mum's tummy and then the doctor will take it out with a knife'.*

The analysis of children's responses about how babies are born showed a remarkable improvement after the teaching intervention. In the post-interviews, everyone (60/60) recognized the biological contribution of both parents (Table 2) by explicitly appealing to the 'union of mum's egg & dad's sperm':

- *'Dad has the sperm and mum has the egg and these will merge and the baby will grow in her tummy and the doctor will get it out … the bear-doctor'.*
- *'The baby will be made with sperm and egg. Dad has the sperm. Mum has the egg. These merge and the baby is made'.*

In order to explore the statistical significance of the improvement in children's reasoning about reproduction, we performed a McNemar's test with the desired claim ('both parents') vs. the undesired claim ('*not*-both parents': 'mother' (only) and 'don't know'). The two-tailed p-value was less than .0001, so the difference in the appearance of the desired/undesired claims before and after the intervention is considered as statistically significant. A second McNemar's test was performed *within* the category of the desired claim itself, with the actual *target* claim ('both parents_bio contribution') vs. the *non-target* claim ('both parents_M bio & F psycho contribution'). The difference in the appearance of the target/non-target claims before and after the intervention was found to be statistically significant, too ($p < .0001$).

Results about Research Question II

Species resemblance mechanism. All participants were able to understand that species remains constant from generation to generation even before the teaching intervention. In fact, in the pre-interviews 60/60 children came up with 3/3 correct families by putting next to each of the three animal couples a baby animal of the same species. What is worth noticing though is the type of criteria they used for justifying their same-species families (Table 3).

Children's justifications for coming up with families of the same species in their pre-interviews may be divided into (a) those that focused *exclusively* on 'biological family-rules' such as 'X-gives-birth-to X', 'family members have similar appearance', or both (45/60), and (b) those that, even when they had a reference to some 'biological family-rule', did consider 'social family-rules' (e.g. 'family members share a common living place', 'family members don't eat one another' (7/60)), or did not consider any rule at all (8/60) (Table 3):

- *'I made the fox-family … I put the baby-fox with these parents because they are foxes. Foxes have a fox-baby … they make fox-babies only' (no idea about why).*
- *'I put the penguin-baby with the penguins because they are its parents because they have the same face. And the same fair … the colour is the same' (no idea about why).*

Table 3. Children's justifications about 'parents–offspring' species resemblance

	Bio family-rules	Mixed family-rules (social/bio)	Don't Know
Pre-interviews	45/60 (75%)	7/60 (11.7%)	8/60 (13.3%)
Post-interviews	59/60 (98.3%)	1/60 (1.67%)	0/60 (0%)

- *' … I didn't put the penguin-baby with the couple of lions. The penguin-baby lives on ice, and they live in the jungle. They cannot be a family … they are not the same animals.'*
- *' … I didn't put the baby-fox with lion-parents because lions eat foxes and they will eat the baby-fox … If they didn't eat foxes … God wouldn't let them to have a different baby … But they will eat this baby, they can't be a family.'*

In the post-interviews, almost all children (59/60) justified the species resemblance of families through 'biological family-rules' (Table 3). Fifty-three children focused exclusively on 'species-genes', while three combined 'species-genes' with the rule 'X-gives-birth-to-X':

- *'I put the baby-lion with the lion-parents because they have the lion-genes and they cannot have a different baby if they don't have different genes.'*
- *'I put the baby-penguin with the penguins because they all have the same genes … the penguin-genes … Penguins cannot have a baby-fox because they don't have the same genes with it.*
- *' … I didn't put the foxes with the baby-lion, because they are not the same animals … The fox-parents have the fox-genes … dad has them in his sperm and mum in her egg … mum's egg and dad's sperm make the baby … they have the fox-genes in them and so the baby has the fox-genes, too. The foxes can only have baby-foxes.*

In order to explore the statistical significance of the improvement in children's reasoning about 'parents–offspring' species resemblance, we performed a McNemar's test with the desired justification ('biological family-rules') vs. the undesired justification ('non-biological family-rules': 'social family-rules' and 'don't know'). The two-tailed p-value was equal to .0005, so the difference in the appearance of the desired/non-desired justifications for species resemblance before and after the intervention is considered as statistically significant. A second McNemar's test was performed *within* the category of the desired justification of 'biological family-rules' itself. The test was performed with the *target* justification ('both parents bio_species-genes') vs. the *non-target* justification ('both parents bio_not species-genes': 'X-gives-birth-to-X' and 'similar appearance of family members'). The difference in the appearance of the target/non-target justifications before and after the intervention was found to be statistically significant, too ($p < .0001$).

Table 4. Children's claims about the influence of parents' wish on offspring's species

	Unfulfillment of parental wish	Fulfillment of parental wish
Pre-interviews	42/60 (70%)	18/60 (30%)
Post-interviews	60/60 (100%)	0/60 (0%)

Parental wish and offspring's species. In the pre-interviews, most of the participants (42/60) appeared to understand that parents' intention/wish cannot influence the child's species. Nevertheless, there were also some children (18/60) who appeared to believe the opposite (Table 4).

Focusing on the former, we note that 36/42 justified their predictive claims for 'same species regardless of different parental wish' by appealing to the 'biological family-rule' 'X-gives-birth-to-X'. The remaining 6/42 either appealed to the 'social family rule' of sharing a habitat (2/6) or did not provide any justification at all (4/6):

- *'If the foxes wanted very much to have a lion-baby and were making this wish all the time … they can't have a baby-lion … because they are not the same … the same animals.*
- *'Their wish won't come true. The lion parents will not have a penguin-baby. This baby lives in North Pole and these parents don't live there.*

Finally, those 18/60 children who claimed in their pre-interviews that the parental wish for offspring with a different species may come true appealed mainly to the power of wish or God:

- *'If the lion parents want very much to have a penguin-baby kai wish it night and day … yes, if the make their wish politely then they can the baby they want … If the wish is rude, the lions cannot have the penguin-baby, but if it is polite they can.*
- *'If they make their wish when they see a star falling from the sky, then they can have the baby they want. The lions can have a fox-baby because it is their wish … you wish something and it then it happens.*
- *'If the penguins wish all the time to have a baby-fox … If they want it very much, they will have a baby-fox because God can give it to them.*

In the post-interviews, all children rejected the fulfillment of the parental wish for offspring with a different species (Table 4). This was grounded on two 'biological family-rules': 'X-gives-birth-to X' (4/60) and 'species-genes' (56/60):

- *'The wish of the penguins will not come true. They will not have a fox-baby, because a fox-baby is another animal, it is not like them.*
- *'If the penguins wanted to have a mouse-baby, they can't. If they make a wish, they can't. They don't have the mouse-genes. They have the penguins-genes.'*
- *'If the lions want very much to have a penguin baby, they will not have it. Because they don't have the same g e n e s! Lions have the lion-genes and penguins have the penguins-genes.*
- *'Lions can't have a penguin baby. The baby is made with the egg of the mum-lion and the sperm of the dad-lion. Mum's egg and dad's sperm are united and make the baby … Inside them they have the lions-genes. They make a lion baby with the lions-genes; they can't make a penguin-baby.*

In order to explore the statistical significance of the improvement in children's reasoning about the possible contribution of the parental wish to the offspring's species, we performed a McNemar's test with the desired claim ('wish unfulfillment') vs. the not desired claim ('wish fulfillment'). The two-tailed *p*-value was less than .0001, so the difference in the appearance of the desired/non-desired claims for the wish before and after the intervention is considered as statistically significant. A second McNemar's test was performed *within* the category of the desired claim about wish unfulfillment itself, with the *target* justification ('species-genes') vs. the *non-target* justification ('not species-genes': 'X-gives-birth-to X', 'Habitat' and 'don't know'). The difference in the appearance of the target/non-target justifications before and after the intervention was found to be statistically significant, too ($p < .0001$).

Results about Research Question III

Body traits resemblance mechanism. Most of the children were able to understand that offspring are more likely to share body traits with their parents than with others, even before the teaching intervention. In fact, in the pre-interviews, as shown in Table 5, only a few claimed that the child would have the usual body-trait of all people instead of the peculiar one of his/her parents: 2/60 in the bones-task, 9/60 in the eye-brows-task, 3/60 in the ears-task and 11/60 in the heart-task (for details about these tasks, see Appendix 1).

In the pre-interviews, the desired claim about 'parents–offspring' shared body traits was grounded on 'biological family-rules' like the similar appearance of family members or child's birth by the parents, with the former being more frequent than the latter:

- *'The child will have very strong bones like the parents, because he must be the same with them.'*
- *'Their child will have very strong bones like them, because he will be born by his mum and when a parent has very strong bones, the child has very strong bones too.'*

On the other hand, those who did not seem to recognize the 'parents–offspring' body traits resemblance in their pre-interviews (Table 5) appealed either to the trait itself (i.e. its advantage/disadvantage for the child), or to the high frequency of the trait's alternative version in the species:

- *'The child will have eyebrows. It doesn't matter that the parents do not have them. The child will have them so that the sweat won't fall into its eyes.'*
- *'The child will have eyebrows because all other people have … His parents don't have eyebrows, but all the others have them and the child will have them too.'*

In the post-interviews, almost all children who made the desired prediction about the parents–offspring shared phenotype justified it by appealing to the idea of 'trait-genes': 56/58 in the bones-task, 51/57 in the eyebrows-task, 55/58 in the ears-task, and 55/59 in the heart-task:

- *'The child will be born with black heart. His mum gives birth to him with a black heart, because the black-heart-genes are together … Mum's egg and dad's sperm merge and the black-heart-genes are inside them and the little heart of the baby will be black.'*

Table 5. Children's claims about 'parents–offspring' body traits resemblance

	Parents' body-trait				Others' body-trait				Don't Know			
Task	3.1	3.2	3.3	3.4	3.1	3.2	3.3	3.4	3.1	3.2	3.3	3.4
Pre-interviews	43	41	38	38	2	9	3	11	15	10	19	11
	71.7%	68.3%	63.3%	63.3%	3.3%	15%	5%	18.3%	25%	16.7%	31.7%	8.3%
Post-interviews	58	57	58	59	1	1	1	1	1	2	1	0
	96.7%	95%	96.7%	98.3%	1.67%	1.67%	1.67%	1.67%	1.67%	3.33%	1.67%	0%

Table 6. Children's consistency regarding (a) the desired claim (DC: 'parents' trait') and (b) the desired justification (DJ: 'bio family-rules') about offspring's body traits

	Inconsistent use		Consistent use	
	DC	DJ	DC	DJ
Pre-interviews	13/60 (21.7%)	18/60 (30%)	44/60 (73.3%)	35/60 (58.3%)
Post-interviews	1/60 (1.67%)	3/60 (5%)	59/60 (98.3%)	57/60 (95%)

- *'The child will be born with the ears of its parents … because mum's egg and dad's sperm will make the child … These have the strong-ears-genes … the egg and the sperm.'*
- *'The child will be without eyebrows because it will have the without-eyebrows-genes. The parents have them and so it has them too.'*

Moreover, those who did not appeal to 'trait-genes' *did* appeal to the more naïve but still *biological* 'family-rule' of 'similar appearance within families':

- *The child will be without eyebrows to look like his parents. If he had eyebrows, he would ask his mother 'Mum, why you don't have eyebrows like I do?'*
- *'The child will have black heart because his parents are the same.'*

In order to explore the statistical significance of the improvement in children's reasoning about 'parents–offspring' body traits resemblance and the mechanism through which it derives, we performed two McNemar's tests. These had to do with (a) the consistent vs. inconsistent appearance of the desired claim ('parents' trait') in the pre- and post-interviews (Table 6), and (b) the consistent vs. inconsistent appearance of the desired justification ('biological family-rules', which actually includes the target justification 'parents' trait') (Table 6). By consistent appearance of a claim or justification we mean its appearance in three or four relevant tasks, while by inconsistent we mean its appearance in only one or two. McNemar's test for (i) showed that the difference in the consistent appearance of the desired claim ('parents' body-trait') before and after the intervention is extremely statistically significant ($p = .0015$). The same is valid for the difference between the consistent appearance of the desired justification ('biological family-rules') in the pre- and post-interviews, too ($p = .0001$).

Parental wish and offspring's body traits. Parents' wish seems to be more powerful when it concerns the body traits rather than the species of the offspring. In the pre-interviews, in each of the four tasks, almost half of the children claimed that parents' intention/wish can influence an offspring's body traits. Nevertheless, in the post-interviews almost all rejected the power of wish (Table 7).

Table 7. Children's claims about the influence of parents' wish on offspring's body traits

	Unfulfillment of parental wish				Fulfillment of parental wish				Don't Know			
Task	3.1	3.2	3.3	3.4	3.1	3.2	3.3	3.4	3.1	3.2	3.3	3.4
Pre-interviews	28	25	25	22	28	32	32	37	4	3	3	1
	46.7%	41.7%	41.7%	36.7%	46.7%	53.3%	53.3%	61.7%	6.7%	5%	5%	1.67%
Post-interviews	58	58	60	59	2	1	0	1	0	1	0	0
	96.7%	96.7%	100%	98.3%	3.3%	1.67%	0%	1.67%	0%	1.67%	0%	0%

Those who rejected wish fulfillment from the beginning appealed to the similar appearance of family members, that is, to a 'biological family-rule':

- *'Like those of the parents, the regular bones. The wish won't come true. If they had non-breaking bones, they would have a child with non-breaking bones. Now they will have a child with regular bones, because they have regular bones.'*
- *'The child must not have eyebrows. It must look like the parents. The wish isn't important.'*
- *'The child will have regular ears because the parents have regular ears. They are the same.'*

On the other hand, those who appeared to believe in the wish fulfillment (Table 7) drew mainly on the power of the wish or God:

- *'The child will have strong ears, because it is a wish. The parents made this wish and it will happen.'*
- *'The child will have eyebrows, because if they make a wish it can come true. The child can be different from the parents because they will make the wish.'*
- *'It will be born with very strong ears. Christ will listen to the wish mum and dad make.'*
- *'God will do what they will ask him to do.'*

Finally, in the post-interviews, almost all who made the desired prediction about the wish unfulfillment justified it by appealing to 'trait-genes': 52/58 in the bones-task, 54/58 in the eyebrows-task, 55/60 in the ears-task, and 55/59 in the heart-task. In their own words:

- *'The wish will not happen. Because the parents have the black-heart-genes. The child will have a black heart. If they had the red-heart-genes, then it would have a read heart.'*
- *'Regular ears because they have the genes. The regular-ears-genes. They will merge … the egg and the sperm. And they have inside them the genes. The baby will be created and it will be like the regular-ears-genes … it will be with regular ears.'*

Moreover, those very few children who did not appeal to 'trait-genes' appealed to the more naïve but still '*biological* family-rule' of 'similar appearance within families':

Table 8. Children's consistency regarding (a) the desired claim (DC: 'wish unfulfillment') and (b) the desired justification (DJ: 'bio family-rules') about parental wish and offspring's body traits

	Inconsistent use		Consistent use	
	DC	DJ	DC	DJ
Pre-interviews	16/60 (26.7%)	14/60 (23.3%)	21/60 (35%)	17/60 (28.3%)
Post-interviews	1/60 (1.67%)	2/60 (3.3%)	59/60 (98.3%)	58/60 (96.7%)

- *'Without eyebrows because the parents don't have eyebrows and the baby will not have eyebrows. The baby must have whatever its dad and mum have. The wish doesn't matter.'*

In order to explore the statistical significance of the improvement of children's reasoning about 'parents–offspring' body traits resemblance and the wish contribution to it, we performed two McNemar's tests. These had to do with (a) the consistent vs. inconsistent appearance of the desired claim ('wish unfulfillment') in the pre- and post-interviews (Table 8), and (b) the consistent vs. inconsistent appearance of the desired justification ('biological family-rules', which actually includes the *target* justification 'body traits genes') (Table 8). By consistent appearance of a claim or justification we mean its use in three or four relevant tasks, while by inconsistent we mean its appearance in only one or two. The first McNemar's test showed that the difference in the consistent appearance of the desired claim before and after the intervention is extremely statistically significant ($p = .0002$). The same is valid for the consistent appearance of the desired justification, too ($p = .0019$).

Discussion

Our informants seem to have built a satisfactory understanding of reproduction. At the outset, only half of them (31/60) recognized some paternal role in a child's creation and less than 1/3 of those who did it (9/31) had a *biological* role in mind. On the contrary, after the teaching intervention, all the children (60/60) were able to recognize the contribution of both parents by appealing to biological 'entities' such as sperm and egg.

According to our findings, children had also the chance to advance their reasoning about the parents–offspring species resemblance. Although they seemed to be at a good point from the beginning—all of them had recognized the 'parents–offspring' species resemblance and most of them (45/60) had grounded it exclusively upon biological 'family-rules' such as 'X-gives-birth-to X' and 'family members have similar appearance'—the use of the idea of 'species-genes' as the *dominant* biological 'family-rule' after the teaching intervention dictates a significant progress.

This is also valid for children's reasoning about parents–offspring resemblance in body traits. In the pre-interviews, most of them claimed that the child would have the peculiar body traits of the parents rather than the usual body traits of the species and they also did this by appealing to biological 'family-rules' such as birth or similar appearance of family members. Nevertheless, the use of the 'trait-genes' idea as the *dominant* biological 'family-rule' after the teaching intervention suggests a significant progress as well. The effectiveness of the teaching intervention in supporting children to advance their reasoning about physical family resemblance is also indicated by the increase in the consistency in the appearance of *both* the desired claim about the offspring's phenotype ('parents' trait') *and* the desired justification for it ('biological family-rules' among which the target idea of 'trait-genes').

Finally, the idea of 'species-genes' or 'body-trait-genes' appeared to provide a solid ground for rejecting the contribution of the parental intention/wish for the offspring's species or body traits. In the post-interviews, the idea of 'species-genes' was used by most of the children (56/60) in order to reject the possibility that parents may affect the species of their child by their intention/wish. Likewise, the idea of 'body-trait-genes' was used by most of the children (52–55 across tasks) in order to consistently reject the possibility that parents' intention/wish may affect the body traits of their child.

Thus, inheritance may not be too abstract for young children after all. Their remarkable ability to reason about it when they are appropriately supported seems to undermine the idea that its abstractness may be nothing but prohibitive for them. Appearing ready to substitute naïve 'family-rules' like 'X-gives-birth-to-X' or 'family members have similar appearance' with a rudimentary but still *less* naïve idea of 'genes' in order to (a) explain why offspring share the same species or the same body traits with parents and (b) reject the power of parents' wish to influence offspring's species or appearance, the young informants of the study made clear that they *can* actually *deal* with inheritance on a very basic level.

Unlike what Schroeder et al. (2007) suggested, an early introduction of a very simplified version of the idea of genes may be feasible. And we do not refer only to the maternal genes like Solomon and Johnson (2000) did, but also to the paternal ones. In fact, it is *this* basic conceptualization of 'genes' as little 'things' that pass from both parents to offspring that may strike rather effectively the abstractness of inheritance.

Of course, the gene concept is extremely demanding even for much older children (Lewis & Kattmann, 2004). Nevertheless, one should take into account the key difference between (a) understanding a demanding concept and (b) using a very simplified version of it just to hold basic reasoning strands in place (cloth pegs for keeping laundry hanging on the drying rack may provide a helpful analogy). We do not suggest that our results indicate a meaningful understanding of the gene concept on children's behalf. Such an understanding could not even be a legitimate learning objective for their age in the first place. However, what we *do* suggest is that young children seem ready to use a rudimentary, essence-like idea of genes in order to organize biologically oriented reasoning strands about family resemblance.

This readiness may have emerged within a specific teaching intervention with carefully designed learning activities of age-sensitive content and type. However, it is worth mentioning per se as well. Young children's competencies have been underestimated for long through the Piagetian conceptualization of cognitive development and its emphasis on age-related, domain-free constraints in their thinking (Inagaki, 1992). Adding—through empirical studies—to the more optimistic post-Piagetian view, which has shifted focus to children's domain-specific reasoning competencies (Inagaki & Hatano, 2002), seems to be important. As Metz (2011) pointed out, science education research underlines quite often what children *cannot* learn instead of what they *can*. The evidence-based enhancement of the idea that kindergarten can be more than a playground for young children can contribute to a better start in their systematic exploration of the natural world.

Going back to children's readiness regarding inheritance in particular, we should note some possible implications for preschool teachers' practice and training. Children's emergent potential seems to give teachers a kind of 'green light' for trying to explore aspects of inheritance which have traditionally been considered as inappropriate or too hard for a preschool class. On the other hand, the demanding didactic transpositions in which teachers need to be engaged for this topic confirm their need for a solid background of 'Pedagogical Content Knowledge', which has to include a satisfactory understanding of living organisms.

Finally, since young children show a rather remarkable potential in starting developing a more elaborated understanding of inheritance, one might possibly consider the idea of introducing more realistic inheritance models where offspring derive from parents with different traits and thus different trait-genes. According to Terwogt, Stegge, and Rieffe (2003), some 4–5-year-olds can actually choose a 'combined phenotype' for the offspring vs. a 'mother look-alike' or a 'father look-alike' phenotype. And they do this in a rather consistent way, at least when no biases about one of the parents are introduced by the researchers. So, it seems interesting to continue research with exploring whether preschoolers may be supported in developing essential explanations about offspring's hybrid appearance and how: might the 'battle of genes' within the united sperm and egg become a new 'conceptual peg' for them in a new, appropriately designed teaching intervention or not?

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Appendix 1. Interview protocol

- 2.1. Example

If children made correctly, for example, the penguin family, they were asked to explain why they put the baby-penguin with the couple of penguins and not with the couple of lions. If they claimed they did not do the latter because penguins live in the North Pole and lions in the jungle while families should live in the same place, the interviewer was engaged in challenging them through 'what … if' questions: 'But what if the penguins and the baby-lion *could* live in the same place? What would you think then? Could they be a family? Could these penguins be the parents of this baby-lion? Why?'

- 2.2. Example

The interviewer picked up the card with the penguin couple and told the child that 'these penguins love each other very much and want to have a baby, but their wish is to have a baby-rabbit and not a baby-penguin. So, every day they make the wish to have a baby-rabbit with all their heart. What do you think? Can these penguins have a baby-rabbit as they wish? Why?'

- 3.1–3.2. More information

In task 3.1, children were asked to make four families by considering inborn physical traits which were peculiar for the species but present in both parents. Similarly in task 3.2, children were asked to make four families by considering inborn physical traits which were also peculiar for the species, absent from both parents but very desirable by them for their child. The internal or external traits for both tasks appeared as either 'good' or 'bad': (a) non-breaking bones ('good' trait), (b) no eyebrows ('bad' trait), (c) very sensitive ears ('good' trait), and (d) black, weak heart ('bad' trait). The 'nature' of the trait was manipulated, since children were reported to use it as a judgment criterion (Solomon et al., 1996). In task 3.2 parents always appeared to have the 'bad' version of the trait and to wish the 'good' one for their child, so that the story would be plausible.

- 3.1 –3.2. Examples

3.1: 'People have usually a red heart. But there are two people, a man and a woman, who were born with a black heart which is weak and does not work well, so they get tired very easily. This couple with the black weak heart is going to have a child of their own. Do you think that their child will have a black weak heart like they do when he or she will grow up or a regular red heart like those of all the other humans? Why do you think so?'
3.2: 'Two other humans, a man and a woman, who were born with regular ears, are going to have a child. They both want very much for their child to have very strong ears that hear perfectly all sounds even the very low ones. So, they make this wish every day with all their hearts. Do you think that their child will have

regular ears like they do when he/she will grow up, or very strong ears like the ones they wish for it? Why do you think so?'

Appendix 2. Teaching intervention

- Part I

Children made five animal families using the cards they were provided (activity 1.1), were told a reproduction story with the aid of relevant cards (1.2), and were engaged in explaining why parents of one species cannot have children of another (1.3). Their inability to come up with adequate explanations gave meaning to a story-based introduction of the idea of 'species-genes' like 'very tiny things' located in the 'mum's egg and dad's sperm' (1.4).
After this, children took part in a drawing activity in order to create their own visual representation of the sequence of events: (a) they started from the parents of a certain species and their 'egg & sperm' that contain the 'species-genes', (b) proceeded with bringing together the (species-genes containing) egg & sperm, and (c) ended up with a tiny baby in mum's tummy, created with the 'egg–sperm' union and thus having the same 'species-genes' that were in them (1.5). Finally, children were engaged in a role-play activity where they had to dress and act as the participants of a story according to which a couple of certain animals (rabbits) wanted to have a child of another species (baby tiger, baby frog, or baby mouse) (1.6). In all 6 activities of this part, children were engaged in explanations of what they did or said.

- Part II

Children got familiar with the idea of 'body traits-genes' through a story ('How I came to the world with blue eyes, while my parents wished that I came with brown') (2.1). When listening to it, they were required to be active by answering questions about several body traits of the baby except the eye color and whether these could be influenced by the parents' wish. Destabilizing intentional reasoning was also attempted through a floor-game (2.2) where children had to make justified predictions about whether the child would have a series of body traits that the parents wished for although they did not have them themselves.

- Part III

Children were engaged in a three-case, puppet-show activity (3.1): they watched three couples of animals (hippos, elephants, and giraffes) that were supposed to make their first visit to the foster family of their child (tiger family, giraffe family, and zebra family) worrying about whether it would have acquired the species of the foster family. Then children were asked for their own opinion. In one of these cases, the adopted child itself wished to acquire the species of its foster family in order to fully fit and the participants were asked to explain to the child why this was not actually possible.

The last activity (3.2) was based on a three-case story where children were told about three human couples, each with a specific body-trait (brown eyes, very short eyelashes, and very quick-digesting stomach), that gave birth to a child. Children were first required to make a justified prediction about the child's phenotype with regard to these traits; the aim was to engage them in appealing to the trait-genes within 'mum's egg and dad's sperm' that gave rise to a child. A second justified prediction was also required from children. This had to do with whether the trait in question would remain intact if the child was adopted by a family that had an alternative version of it (blue eyes, long eyelashes, and regular stomach). In one of these cases, the adopted child himself or herself wished to acquire the trait of the foster family to show his or her love and children were asked to explain why this was not actually possible.