teaching preschoolers about inheritance

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ABSTRACT
This study aimed to promote advanced reasoning about biological inheritance in four- and five-year-olds. A total of 78 preschoolers (Experimental $n = 40$; Comparison $n = 38$) completed pre- and post-test versions of two biological reasoning tasks. The Experimental condition received 15 lessons on biological inheritance, whereas the Comparison condition received regular story time activities. The results showed that the Experimental group outperformed the Comparison group at post-test. Overall, the results are an encouraging indication that an increased understanding of biological inheritance can be effectively supported in preschool years.

KEYWORDS biological inheritance, preschool, reasoning, science curriculum

There is considerable debate within the literature about the type and content of theories that young children hold about biology (Carey, 1985; Wellman and Gelman, 1998). Some researchers have assumed preschoolers have no causal biological theories at all, and rely on domain-general theories to reason about biology (Piaget and Inhelder, 1969; Carey, 1985). An alternative view put forth by other theorists suggests that preschoolers hold domain-specific causal theories, which form an innate, naive understanding of biology (Wellman and Gelman, 1998). Within this view, children’s naive theory of biology acts as a coherent framework employed to explain phenomena such as bodily functions and illness. The acquisition of biological concepts is a necessary component of conceptual development within a domain, but development must include the
reorganization of these concepts so children understand how they are causally related to each other.

Because preschoolers hold domain-specific causal theories of biology, they are developmentally equipped to learn about biological inheritance. It is believed that incorporating biology in the preschool classroom can compliment children's early learning and has the potential to support developmental change. There is, however, a relative paucity of research in the area of science curriculum development for children this age, particularly in the area of biology (Krogh, 1990; Worth and Grollman, 2003; French, 2004).

The present study focused on testing a biological inheritance unit designed to promote advanced reasoning of biological inheritance in preschoolers. Inheritance is specifically related to biology because only living things have the ability to transmit biological features from one generation to the next. In order to design an instruction program, it was critical to establish 1) what an adult-like understanding of biological inheritance is, and 2) in what way preschoolers' understanding differs from the understanding of adults.

Solomon et al. (1996) determined there are at least three concepts that individuals must possess to have a rough adult-like understanding of biological inheritance. First, they must appreciate that mental and bodily traits are ontologically distinct. That is, they understand that one’s desire and learning can change psychological traits but not physical traits. Second, they must understand that offspring tend to resemble their biological parents (i.e. cats have kittens), and third, they should know that babies come from mothers’ wombs. A review of the literature suggests that children as young as four years of age appear to possess an adult-like understanding of biology, based on the criteria described above. First, they understand that mental and physical traits differ (e.g. Inagaki and Hatano, 1993; Kalish, 1997). For example, Inagaki and Hatano (1993) demonstrated that children aged four and five recognized that bodily characteristics such as eye color were not modifiable by intentions alone. Second, children expect offspring to physically resemble their parents based on birth and biological relatedness (e.g. Springer, 1992; Carey and Spelke, 1994; Solomon et al., 1996; Solomon, 2002). For example, Springer (1992) found that four- and five-year-olds were more likely to judge animals of the same family to share biological features even when the related animals were physically dissimilar. Finally, research also suggests that many preschoolers, if not all, know that babies come from their mothers' wombs (Bernstein and Cowan, 1975; Springer, 1995).

Although most young children possess these concepts of inheritance, Solomon et al. (1996) argued possession is not sufficient to demonstrate a full-blown adult understanding; instead, it is an understanding of the relation between these concepts (i.e. a framework) that is required. The lack of a coherent framework in preschoolers is evident on certain tasks, where they make judgments that are inconsistent with those of adults (Solomon et al., 1996; Springer, 1996; Johnson
and Solomon, 1997; Weissman and Kalish, 1999; Solomon, 2002). Studies that explore children’s intuitions about inherited traits when animals are switched-at-birth or adopted have provided inconsistent evidence. Solomon et al. (1996) found that children under the age of seven are just as likely to expect adopted children to resemble their biological parents on physical and psychological traits as their adoptive parents. Also, research suggests that preschoolers believe maternal intentions and desires can play a role in their inheritance. Weissman and Kalish (1999) contrasted traits mothers possessed (e.g. blue eyes) with traits they desired for their unborn children (e.g. brown eyes). Four- and five-year olds often erroneously accepted the ability of maternal intentions to affect offspring traits. Finally, research suggests preschoolers have difficulty differentiating between the effect of acquired (environmental influenced) and inborn traits on offspring (Kargbo et al., 1980; Engel Clough and Wood-Robinson, 1985; Springer and Keil, 1991; Springer, 1992, 1995, 1996).

In sum, many children possess isolated concepts of biological inheritance by time they are the age of five. They distinguish between the effects of the environment on physical and psychological traits, and they tend to predict that offspring will resemble their parents because they come from their mother's wombs. Despite knowing these fundamental concepts, preschoolers are still limited in their knowledge and experience and have not formed a cohesive framework. Thus, they make incorrect predictions on biological inheritance tasks that require them to make a causal link between inherited traits and the birth process.

facilitating conceptual reorganization

Although conceptual coherence is a criterion required to possess a separate domain of biology (Wellman and Gelman, 1992), there is little understanding of when children’s early conceptualizations combine into a coherent theory. Solomon and Johnson (2000) argued that teaching children an isolated concept makes little sense unless they are able to relate the concept to a set of other beliefs and understand how the concepts are interrelated. If children make causal links among concepts, it would be expected that they might do better on tasks that are made deliberately complex and elaborated such as switched-at-birth tasks (Wellman and Gelman, 1992).

Springer (1995) posited that in order for children to make inferences about inheritance, they must possess three premises: a) babies grow inside their mothers, b) fetal growth is not typically affected by extra-uterine influence, and c) physical proximity between two objects facilitates, but does not guarantee transmission of properties between them. Based on these three premises, Springer suggested that three beliefs can be inferred. Belief one is that babies share more physical traits with biological mothers than unrelated animals. Belief two is that offspring can inherit both desirable and undesirable traits. And, belief three
is that inheritance occurs by means of maternal transfer. Springer hypothesized that gaps in children's understanding of biological inheritance can be bridged if the three premises are understood. After asking children a series of questions based on the premises and beliefs, he found that a majority of the children in the study who possessed the premises also had a naïve theory of kinship. In addition, there was evidence of a direct relationship between possessing the three premises and accepting the beliefs. He also found that after teaching three- and four-year-olds the basic facts about prenatal development, the premise that babies grow inside their mothers was a strong predictor of whether or not children would accept the naïve theory of kinship. The results of a subsequent study (Springer, 1996) supported earlier findings by demonstrating that four- to seven-year-olds who knew where babies grow were more likely to correctly judge the relatedness of the babies to their biological parents despite differences in physical similarity. Springer suggested that acquiring this concept allows children to make theoretically based predictions about inheritance even though their knowledge is limited. However, Springer does not claim that children have a complete biological theory; instead, he suggests that understanding certain concepts allows children to make some correct biological inferences.

instructing biological inheritance

Solomon and Johnson (2000) devised a teaching intervention for five- and six-year-olds to support a coherent understanding of biological inheritance similar to that of adults. The strategy proposed by Solomon and Johnson, and utilized in the present study to effect conceptual change was as follows. First, children were made aware that they lack complete understanding of inheritance concepts. Then, once this awareness developed, they were supplied with relevant information. The specific concepts covered in the intervention, which were built around Springer's (1995) naïve theory of kinship, were as follows: a) offspring tend to resemble their parents; b) inherited (physical) traits stay constant throughout life regardless of environmental influence; c) physical form is determined at birth and cannot be altered during the life span; d) inborn (physical) traits are not changeable through teaching or learning or by intentions; e) there is a physical link between mother and child via the womb; and f) adoption.

Solomon and Johnson (2000) proposed that conceptual coherence could be facilitated by presenting children with a rudimentary notion of genes, a ‘conceptual peg’ around which they can organize concepts. It was suggested that children could use the notion of ‘genes’ as a causal mechanism for linking the process of birth to why offspring resemble their parents on some traits but not others. Following instruction, more children in the training condition made more adult-like patterns of responding on inheritance tasks. However, Solomon and
Johnson (2000) were unable to conclude if knowledge of 'genes' was responsible for the improvement of children's judgments on measures.

The instruction unit used in the present study was designed to be developmentally appropriate for preschoolers. Case (1993) asserted instruction should consider the cognitive structures children currently hold, and build on these existing structures by providing information that is slightly developmentally advanced. Following previous research (Springer, 1995, 1996; Johnson and Solomon, 1997; Williams and Affleck, 1999; Solomon and Johnson, 2000), children's literature was used to link prior knowledge with new information by triggering existing cognitive structures, and then by serving as a platform for discussion and questions. Case (1993) also asserted that limited memory capacity may impede children's ability to cognitively advance. Previous research suggested ‘multi-modal scaffolding’ can reduce memory demands and enhance children's learning (Gambrell and Jawitz, 1993; Gordon et al., 1998; Shafrir, 1999; McKeough et al., 2005). Based on this research, presentation of inheritance concepts was supported with the aid of verbal (i.e. oral and written), graphic (i.e. pictures), and kinesthetic (i.e. manipulatives, dress-up, coloring) activities.

The present study

The first aim of the present study was to determine if preschoolers' understanding of inheritance could be advanced without introducing the developmentally advanced concept of genes. This position was advocated by Horobin (1997) who noted that it is common even for 10- and 11-year-olds to provide genetic explanations for inheritance that reflect misunderstanding of the genetic process. We reasoned that children might use the term in their explanations but not have a true understanding of the concept.

A second aim of the study was to investigate the lower limits of biological understanding. To this end we included four-year-olds in our sample, along with five-year-olds. Finally, to ensure that children had an opportunity to solidify existing knowledge structures, build on to them, and consolidate the new structure, we extended our training considerably beyond the 20 minutes used by Solomon and Johnson (2000) to included 15 lessons of 20 minute durations.

method

overall design

Directors of four childcare centers in a city in western Canada agreed to participate in the study, and consent forms were distributed to the parents of all four- and five-year olds attending each childcare center. Testing was conducted in areas of the centers that were minimally distracting. At pre-test, each child was
presented individually with two biological reasoning tasks: the Modified Springer–Keil task and the Wish-Fulfillment task (see subsequent description). Between the pre- and post-tests, children in the Experimental condition participated in biological inheritance lessons three times a week for five weeks. Children in the Comparison group participated in regular story time activities at the same time facilitated by their respective teachers. Approximately a week after the lessons were completed, all participants were assessed again using alternate versions of the biological reasoning tasks.

participants

A total of 78 four- and five-year-olds participated in this study. There were 40 preschoolers in the Experimental condition (mean age = 59.3 months, SD = 7.9; 17 boys, 23 girls) and 38 preschoolers in the Comparison condition (mean age = 59.9 months, SD = 6.9; 19 boys, 19 girls). There was no evidence for any differences between the conditions with regard to age ($t$ (76) = 0.3, $p = 0.74$), or gender ($\chi^2(1) = 0.4, p = 0.98$).

assessment tasks and scoring

modified Springer–Keil task

This task is a variation of Solomon and Johnson's (2000) modified version of a task used in Experiment 1 of Springer and Keil (1989). It requires children to distinguish innate traits from acquired physical traits that are a result from life experience. Children were shown eight pictures of animal pairs (e.g. Mr and Mrs Robin) and told a series of stories about these animals possessing traits atypical of their species (e.g. soft beaks instead of normal hard beaks). Children were then told that the animals had a child and asked if they thought the offspring would have the same atypical feature as the parents when they became an adult.

Each pre- and post-test version of the task used different animals and varied on two factors: inborn or acquired, and desirable or undesirable consequences (see Table 1). To illustrate, an innate, undesirable trait is depicted as follows: “This is Mr and Mrs Deer. They were born with light bones instead of normal heavy bones. Because their bones were so light, they weren’t as strong as other deer. Later Mr and Mrs Deer have a son named Darren Deer. When Darren is born, do you think he’ll have light bones, just like his parents, or will he have normal heavy bones like other deer?” Desirability of features was manipulated because both Solomon et al. (1996) and Johnson and Solomon (1997) found children considered it a factor in their judgments, although Springer and Keil (1989) did not. The task was counterbalanced so that each child received two examples of each of the four combinations of the Springer–Keil factors (inborn-desirable,
acquired-desirable, inborn-undesirable, and acquired-undesirable) in a different order. Each correct answer received a score of one, and a total score was divided by eight to produce a correct proportion.

In addition, responses were divided into four categories of response patterns: Generational, Species Bias, Parent Bias, and Mixed. The Generational pattern was considered an adult-like judgment pattern, and required children to judge the offspring to resemble their parents on at least three of four inborn traits and like others of the same species on at least three of four acquired traits. The probability of correctly answering six or more questions by chance is \( p = 0.14 \). Offspring judged to resemble their parents on a least seven of the eight features were categorized as having a Parent Bias, and offspring judged to resemble others in the species on a least seven of the eight features were categorized with a Species Bias. The probability of showing either one of these patterns by chance is \( p = 0.04 \). Finally, children whose judgment pattern met none of the above patterns were categorized as showing a Mixed pattern and was considered random.

**wish fulfillment task**

Four new ‘Wish Fulfillment’ questions were added to the Modified Springer–Keil task based on research that suggests preschoolers believe maternal desires (psychological intention) can play a role in inherited traits (Solomon et al., 1996; Weissman and Kalish, 1999). Children were told stories and shown pictures of adult animals that wished for their offspring to inherit an atypical trait they did not possess. Children judged if the offspring would be born with the traits the parents desired them to inherit. The traits varied on two factors: they were either internal or external, and had either desirable or neutral consequences (see Table 2). Neutral traits were chosen because it was not realistic for parents to want undesirable traits for their children. An example of an external, neutral trait is as
follows: ‘This is Mr and Mrs Tiger. They both have regular blood. When they have a baby they want it to have thick blood. If they wish really hard, when they have their baby, will it have regular blood just like them, or thick blood like they wanted?’ Each version (pre- and post-test) used different animals and one of each combination of traits (internal-desirable, internal-neutral, external-desirable, and external-neutral). Again, the questions were counterbalanced across subjects.

Each correct answer received a score of one and a proportion was calculated out of four. In addition, responses were divided into three categories of response patterns: Inborn Bias, Wish Bias, and Other. Children who predicted the baby would have a trait like the parents (even though the parent wished for something different) on at least three out of four questions were scored as having an Inborn Bias. Offspring judged as possessing traits the parents desired on at least three of the four questions were categorized as having a Wish Bias. The probability of showing either of the two patterns by chance is $p = 0.25$. Judgment patterns that met none of the above patterns were categorized as Other.

### instructional lessons

Mixed-sex groups of five to seven children participated in lessons with the experimenter three times a week in the center's library. There were 15 lessons lasting approximately 20 minutes. A second experimenter observed the lessons to verify the integrity of the instruction and to record the children’s reactions. A summary of the field notes, following the lesson foci, is presented in the following section. An a priori standard of four was set for the acceptable number of missed lessons with make-up lessons given to children when possible. Seven participants did not meet the cut-off, so only their pre-test data were included in analysis.

A majority of the lessons followed a typical story time format. During and following each story, guided questions and discussion related the story to a specified concept. The lessons were designed to challenge children’s assumptions about

| Animal | Wish Feature | Animal | Wish Feature |
|--------|--------------|--------|--------------|
| Turtle | Blue muscles | Donkey | Big heart    |
|        | Short necks |        | Shorter face |
| Panda  | Big ears    | Hippo  | Long tongue  |
|        | Small throat|        | Rough skin   |
| Zebra  | Soft hooves | Penguin| Hard bones   |
|        | Big liver   |        | Big feet     |
| Tiger  | Thick blood | Fox    | Thick fur    |
|        | Black eyes  |        | Small stomach|
Inheritance from questions posed by the experimenter. The children were then provided with the information they required to answer the questions posed by the researcher, and the information was consolidated with an activity. Table 3 contains a brief breakdown of each lesson.

**Results**

**Response to instruction**

The first set of lessons focused on the premise that offspring tend to resemble their parents. Observation notes suggested that the children understood this first concept as well as the concept that physical traits remain stable despite environmental influences. When these concepts were revisited, it was difficult to keep children's attention.

Children's interest was piqued when the lessons introduced the concept that the mother and child are linked via the womb. The book, *When You Were Inside Mommy* (Cole, 2001), starts with a description of a cell that is formed from half of the father and half of the mother. The children are told the cell is smaller than a period at the end of a sentence. Children were very interested in how small they once were (e.g. 'I was really that small?') and examined the illustrations in the book carefully. They asked questions about how the baby gets food and how it breathes. Some children seemed confused about whether animal babies come from inside their mother's too, and whether males could have babies. It was noted that some children already had advanced vocabulary and used the words 'uterus' and 'mammal' when they participated in discussion surrounding this concept. There was also a marked change in their explanations in subsequent lessons. One girl spontaneously said that she had hair like her mom and eyes like her dad. When asked 'Why are babies like their parents and not like someone else?' one child responded it is because 'One part comes from mom and one part comes from dad.' During an activity where they were coloring a baby to match the picture of the mom, one child stated, 'The baby could have a different color of eyes if the dad did.'

The next group of lessons focused on the difference between inborn traits and traits that are acquired through social experience. When children altered their physical appearance to understand the concept that not everything about us is the result of coming from our parents, they understood that they were only altering their surface appearance. One child asked, 'What if you had green hair for real? Would your child have green hair?' When told a story about a woman who is pregnant and hurts her elbows and toes, some of the children thought the baby would have hurt elbow and toes too. Providing the children with more examples challenged this misconception. The children enjoyed telling stories about accidents that happened to them after they were born, showing their
### Table 3: Summary of the Inheritance Lessons

| Lesson | Concept | Book | Activity | Sample Question(s) |
|--------|---------|------|----------|--------------------|
| 1      | Like-begets-like | *Are You My Mother?* (Eastman, 1960) | - Children compared own features to those of their parents. | - How do you know that animal (i.e. cow) is/isn’t the baby’s mother? |
| 2      | Like-begets-like | *Are You My Mother?* | - Matched pictures of adult and baby animals. | - How do you know each baby belongs with each adult? |
|        |          |      | - Compared colored faces of parents with their own features. | - Do you have the same eye color as one or both of your parents? |
| 3      | Physical traits stay constant | *The Ugly Duckling* (Blackaby, 2004) | - Children referred to pictures of swans and ducks while answering questions. | - Could the baby swan have ever been a duck? |
| 4      | Physical form is determined at birth | *The Ugly Duckling & All Kinds of Babies* (Selsam, 1967) | - Matched figurines of adult and baby animals. | - What kind of bird laid the egg, a mommy duck or mommy swan? |
| 5      | Physical form is determined at birth | *All Kinds of Babies* | - Short stories of different baby animals supported with pictures and accompanying questions. | - Could X animal grow up to be a Y instead? Why not? |
|        |          |      | - Colouring activity: draw a line from a baby animal to its mother and color both. | - Even though this animal is a horse, it really thinks sheep babies are cute and sweet. Can the horse decide to have sheep babies? What kind of babies can she have? |
| Lesson | Concept                                                                                       | Book                                               | Activity                                                                 | Sample question(s)                                                                           |
|--------|-----------------------------------------------------------------------------------------------|----------------------------------------------------|--------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| 6      | Physical traits are not influenced by learning or intention                                    | See How They Grow, Foal (Ling, 1992)               | • Put pictures of a horse in various stages of development in order from birth to adulthood. | • If the foal wished really hard, could he grow up to be a cow instead of a horse?          |
|        |                                                                                              |                                                   |                                                                          | • What changed/did not change as the foal grew into a horse?                            |
| 7      | Link between mother and child via the womb                                                    | When You Were Inside Mommy (Cole, 2001)           | • Showed a picture of a lamb and discussed the properties of its fur.    | • Where do babies come from?                                                            |
|        |                                                                                              |                                                   | • Discussed if the lamb could wish to have a cat’s fur instead.          | • Do animal babies come from their mothers’ tummies too?                                |
| 8      | Link between mother and child via the womb                                                    | When You Were Inside Mommy                        | • Coloring activity: children colored adult and baby animals and glued each baby animal inside the adult womb. | • Do you know anyone who has a baby in their tummy?                                      |
| 9      | Children look like their parents because they grow inside their mother’s womb                  | none                                               | • A hand puppet discussed events of a pregnant animal and children catch mistakes (i.e. aliens came out of outer space and put babies in an adult dog...) | • Have you ever seen an animal with a baby in its tummy? What would it look like?          |
|        |                                                                                              |                                                   |                                                                          | • Why do you have the same eye color as your parents?                                   |
|        |                                                                                              |                                                   |                                                                          | • Why are babies like their parents and not someone else?                               |

(table 3 continued)
| Lesson | Concept                                      | Book                                      | Activity                                                                 | Sample question(s)                                  |
|--------|----------------------------------------------|-------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------|
| 10     | Application of knowledge: review             | none                                      | • Created own three-page story about inheritance concepts learned so far. | none                                                |
| 11     | Not all physical traits are a result of coming from one's parents | none                                      | • Altered body appearance with dress-up materials (e.g. wigs, fake noses and body paint). | • You made your skin look a different color using paint, what color is your skin really? |
| 12     | Acquired traits are not passed to offspring  | The Finch Story (Solomon and Johnson, 2000) & The Baby Is Coming | • Discussion with a hand puppet: not everything about us is made from part of our parents. | • When the bird has a baby, will the baby be blue or yellow?  
• Will the baby be born with a hurt toe and elbow? |
| 13     | Acquired traits are not passed to offspring  | none                                      | • Discussion with a hand puppet: review from last lesson.                  | • Did anything interesting happen to your body since you came out of your mother's tummy (i.e. a scar)? |
| 14     | Adoption                                     | David's Father (Munsch, 1983)             | none                                                                      | • David grew in someone else's tummy. What do you think his mother and father looked like?  
• Do you think David could learn how to grow tall like a giant? |
| 15     | Review and summary                          | none                                      | • Drew a picture and dictated a sentence that described what they learned about parents and babies. | none                                                |
scars and bruises. It was emphasized that things that happen to parents by accident are not passed on to their offspring.

The concept of adoption and its implications for inheriting traits was introduced with the story, *David’s Father* (Munsch, 1983). Children enjoyed this story about David who is adopted by a giant. The children were asked what they thought adoption meant. Some of the answers included, ‘If the parents are too young to keep them,’ and ‘My cousin was adopted because her mom died and the dad could not take care of her. My cousin has brown skin and my and her parents have white skin.’

**modified Springer–Keil task**

The mean proportion scores on the biological reasoning tasks, by condition, are presented in Table 4. At pre-test, the mean proportion of correct items for the Experimental condition was not different from that of the Comparison condition, \((t (64) = 0.2, p = 0.83)\). A difference score was calculated by subtracting the pre-test score from the post-test score. Data from five preschoolers were not included in the difference score due to attrition. A sixth participant’s post-test data were removed because the responses were unclear and the tasks could not be scored. A *t*-test comparing difference scores revealed that the Experimental condition had a greater difference score than the Comparison condition, \((t (64) = 2.7, p = 0.01)\). A paired samples *t*-test revealed that children the Experimental group increased in the proportion of correct answers from pre-test to post-test, \((t (32) = 2.7, p = 0.01)\). In contrast, the scores of children Comparison group did not increase greatly from pre-test to post-test, \((t (32) = 1.0, p = 0.35)\). A single-sample *t*-test revealed that the Experimental mean at post-test was above chance \((0.50)\), \((t (32) = 3.7, p = 0.001)\).

The participants’ judgment patterns on the biological reasoning tasks, by condition, are presented in Table 5. When judgment patterns of the Modified Springer–Keil task were analyzed, only five children showed a Generational pattern at pre-test. Because an increase in the number of children with a Generational judgment pattern was one of the goals of the instruction program, the Parent,

| Table 4 | mean scores on the biological reasoning tasks, by condition |
|---------|----------------------------------------------------------|
|         | Springer–Keil     | Wish fulfillment |
| Pre-test| Experimental      | 0.53 (0.15)      | 0.39 (0.42) |
|         | Comparison        | 0.53 (0.14)      | 0.35 (0.37) |
| Post-test| Experimental      | 0.63 (0.19)      | 0.54 (0.38) |
|         | Comparison        | 0.50 (0.13)      | 0.29 (0.32) |
| Difference| Experimental | 0.10 (0.21)      | 0.15 (0.39) |
|         | Comparison        | -0.03 (0.18)     | -0.06 (0.42) |
Adoptive and Mixed categories were collapsed into one category re-labeled ‘Non-Generational.’ A chi-squared test comparing the two conditions in terms of the two judgment patterns (Generational/Non-Generational) showed no evidence of a difference between Experimental (n = 33) and Comparison (n = 33), ($\chi^2(1) = 0.2, p = 0.64$). A chi-squared test comparing the two conditions in terms of the two judgment patterns (Generational/Non-Generational) was conducted to test for the effect of the training condition at post-test. A total of nine children in the Experimental condition were classified as demonstrating Generational judgment patterns who were not Generational at pre-test. This was different from the Comparison group with none of the children showing such a pattern ($\chi^2(1) = 10.9, p = 0.001$).

### Wish fulfillment task

The Wish Fulfillment questions were analyzed separately from the rest of the Modified Springer–Keil task. At pre-test, the mean proportion of correct items of the Experimental condition was not different from that of the Comparison condition, ($t(64) = 0.4, p = 0.70$). A difference score was calculated by subtracting the pre-test score from the post-test score. A $t$-test revealed that the Experimental condition had a greater difference score than the Comparison condition, ($t(64) = 2.1, p = 0.04$). A paired samples $t$-test revealed that children in the Experimental group greatly increased their proportion of correct answers from pre-test to post-test, ($t(32) = 2.2, p = 0.03$). In contrast, the mean proportion of correct answer for children in the Comparison condition did not change from pre-test to post-test, ($t(32) = 0.8, p = 0.41$). However, a single-sample $t$-test revealed that the Experimental mean at post-test was not above chance (0.50), ($t(32) = 0.6, p = 0.57$).

### Table 5: Judgment patterns on the biological reasoning tasks, by condition

| Judgment pattern  | Experimental |  |  | Comparison |  |
|-------------------|--------------|----------------|----------------|-------------|----------------|
|                   | Pre-test     | Post-test      | Pre-test       | Post-test   |
| **Modified Springer–Keil task** |
| Generational      | 3            | 11             | 2              | 0           |
| Species bias      | 8            | 11             | 8              | 14          |
| Birth parent bias | 5            | 2              | 5              | 2           |
| Mixed             | 17           | 9              | 18             | 17          |
| **Wish fulfillment task** |
| Inborn bias       | 10           | 14             | 10             | 5           |
| Wish bias         | 19           | 13             | 21             | 20          |
| Other             | 4            | 6              | 2              | 8           |
To analyze judgment patterns on the Wish Fulfillment task, the Wish Bias and Other categories were collapsed into one category and re-labeled 'Maternal.' A chi-squared test comparing the two conditions in terms of the two judgment patterns (Inborn/Maternal) showed no evidence of a difference between Experimental ($n = 33$) and Comparison ($n = 33$) at pre-test, ($X^2(1) = 0.0, p = 1$). To examine the effect of instruction, a chi-squared test comparing the two conditions in terms of the two judgment patterns (Inborn/Maternal) at post-test was conducted. There was no evidence of a group difference in change of judgment pattern with six out of 23 children in the Experimental condition and three of 23 in the Comparison condition showing an Inborn Bias at post-test who were not Inborn at pre-test ($X^2 (1) = 1.2, p = 0.27$).

**discussion**

The present study investigated the effectiveness of an instruction program that aimed to support advanced reasoning about biological inheritance in preschool-aged children. On the Modified Springer–Keil task, children who took part in the instruction were more likely than the Comparison condition to judge offspring to resemble their parents on those features that were genetically passed on to their parents than traits they had acquired through experience. This finding extends the work of Solomon and Johnson (2000) who demonstrated improvement in the judgment patterns of five- and six-year-olds on this task. Those children who showed a Generational pattern of responding appear to have organized their knowledge so that the causal processes associated with birth were connected to their reasoning about inborn and acquired traits.

On the Wish Fulfillment task, more children in the Experimental than the Comparison condition came to judge that an offspring's physical traits would be unaffected by a mother's desires and wishes. Children in the Experimental group improved in the number of correct answers from pre- to post-test; however, this improvement was not large enough that children were responding at a level above chance (50%). The improvement was also not large enough to change children's response patterns to an Inborn Bias. This result might be due to the indirect way in which this specific concept was addressed in the instruction unit. In the lessons, children had experience determining if animals' personal wishes would affect their inborn traits. For instance, after reading about the first months of a foal's life in *How They Grow – Foal* (Ling, 1992), the children were asked, ‘Do you think if the foal wished really, really hard, he could grow up to be a cow instead of a horse?’ However, at no point did the instruction unit, address the influence of parental desires. The failure to transfer knowledge, in the present case from knowing that personal wishes cannot change inborn physical traits to also understanding the limitations of parental wishes, typically occurs when information is newly acquired (McKeough et al., 1995). Children may not
have consolidated information, which requires reflection and practice, to the point where they were certain about the mechanisms of inheritance. Without a solid understanding of the mechanical processes of birth, the children did not demonstrate a differentiated view of maternal intentions and offspring attributes (Weissman and Kalish, 1999). In sum, the improvement of the Experimental group on the Wish Fulfillment questions provides some support for using instruction to enhance children's reasoning about the limits maternal intentions have on the traits of offspring. However, the indirect nature of the instruction may have limited the magnitude of the results.

Although a number of children who received instruction improved on the number of correct responses on the biological reasoning tasks, there were still children for whom the instruction had no impact. It is possible that the instruction unit did not support these children in forming a coherent framework because the new information was assimilated into an existing framework and did not adequately address their prior misunderstandings. For example, children at this age understand that offspring resemble their parents (like-begets-like). This assumption holds for physical traits, but not psychological traits. When children reason with a like-begets-like principle, they are likely to judge offspring to resemble their respective species regardless of the environment in which they were raised (Gelman and Wellman, 1991; Gelman, 2003). On the Modified Springer–Keil task some children had a Birth Parent response pattern where offspring were judged to inherit the traits of the parents regardless if the trait was inborn or acquired. Children in this category likely used the like-begets-like principle on this task. Thus, it is possible that for those children who persisted with their already established reasoning patterns, the instruction program was not successful in supporting them to make a deeper causal link between the mechanisms of birth and inheritance.

**future research directions**

One issue raised by this study is the need for a greater understanding of a causal mechanism that can facilitate children in forming a coherent framework of biological inheritance. Solomon and Johnson (2000) supplied a rudimentary explanation of ‘genes’ in their training session with the belief that this concept would facilitate learning; however, the effectiveness of this concept as an organizing mechanism was unconfirmed. According to Solomon and Johnson, possessing the concept of birth is not sufficient on its own to form a coherent framework, but it is an important concept for children to possess. Springer (1995, 1996) also argued that children who knew where babies came from were more likely to make correct inferences about other related phenomena.
Based on the findings of the present study, however, it is suggested that the concept of birth plays a more central role in supporting a coherent framework than previously acknowledged (Springer, 1995, 1996; Solomon and Johnson, 2000). The field notes documenting children's reactions to the instruction program demonstrated that this concept was interesting and relevant to them. Children were able to grasp the role of biological connectedness associated with the process of having offspring and even used this information in later explanations and discussions. It is possible that children require an understanding of the processes of birth that has more depth and breadth than the current study provided. Further investigation into the extent that this concept supports children's conceptual understanding of biological inheritance is needed.

**Conclusion**

This study demonstrates that preschool-aged children can be supported to develop an advanced understanding of biological inheritance through the use of instruction. Instruction of biological inheritance concepts is an important way of addressing misconceptions that children have acquired by the time they reach preschool age. The elimination of these misconceptions provides preschoolers with a solid base of knowledge. This is essential, given learners' propensity to assimilate new information into existing frameworks – appropriate or not. In addition, supporting children in the construction of a coherent framework might allow them to link information into a set of concepts that is already organized and assembled for further learning. The assumption here is that these children will be able to learn in the formal educational setting with greater ease and accuracy if they are able to interrelate concepts and understand how they fit together. It is evident from conducting this study that young children are interested in the topic of inheritance and are enthusiastic when they are given an environment that is conducive to learning. The present study is intended as a step toward integrating our knowledge of children's cognitive development with educational curricula development for preschoolers in the domain of biological inheritance.

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**Notes**

1. A 2 (age) × 2 (gender) × 2 (condition) ANOVA revealed a main effect for condition. There was no evidence of other main effects and interaction. Only subsequent $t$-tests are reported.
2. A 2 (age) × 2 (gender) × 2 (condition) ANOVA revealed a main effect for condition. There was no evidence of other main effects and interaction. Only subsequent $t$-tests are reported.
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