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The development of scientific reasoning: Hypothesis testing and argumentation from evidence in young children

Özgün Köksal-Tuncer*, Beate Sodian

Department of Psychology, LMU Munich, Leopoldstr. 13, 80802 Munich, Germany

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ABSTRACT

This study investigates scientific reasoning abilities in 3- to 6-year-old children (N = 67) focusing on their understanding of the relation between causal hypotheses and evidence. Children's evidence generation behaviors and their evidence-based verbal arguments against false causal claims were examined in a blicket detector paradigm. Children were first led to generate and then to test a specific hypothesis about the cause of a light effect. Subsequently, children were presented with two false causal claims in order to elicit evidence-based verbal counterarguments and evidence generation behaviors. The large majority of the children (82%) adopted a systematic hypothesis testing strategy (positive or contrastive testing). Furthermore, 70% of the children provided disconfirming verbal counterarguments and/or selectively generated disconfirming evidence in response to a false claim at least once. In sum, the present study yielded new evidence for scientific reasoning abilities in early childhood.

1. Introduction

Recent research on causal learning in exploratory play in early childhood has been interpreted to support the view "that very young childrenÖs learning and thinking skills are strikingly similar to much learning and thinking in science: Children test hypotheses against data and make causal inferences, they learn from statistics and informal experimentation …" (Gopnik, 2012, p. 1623). In the present paper, we argue that despite much similarity between the way young children and scientists acquire new knowledge (see Gopnik, 2012; Schulz, 2012, for reviews), it is unclear whether and to what extent young children are similar to scientists in terms of intentionally guided knowledge seeking processes that characterize scientific reasoning (Kuhn, 2014).

In our view, the *use* of evidence for the construction and revision of causal beliefs is not to be equated with a metaconceptual *understanding* of the relation of beliefs and evidence. While causal learning can be highly functional even in infants, it takes place without awareness on the part of the infant. Scientific reasoning, on the other hand, which is broadly defined as "the reasoning and problem solving skills involved in generating, testing and revising hypotheses or theories," (Morris, Croker, Masnick, & Zimmerman, 2012, p. 61) is understood as *intentional* knowledge seeking (Kuhn, 2014), and involves "reflection on the process of knowledge acquisition and knowledge change that results from such inquiry activities." (Morris et al., 2012, p. 61).

Early research on development of scientific reasoning in the sense of intentional knowledge seeking has traditionally been seen as a set of skills that do not appear until adolescence (Inhelder & Piaget, 1958; Kuhn, Amsel, & O'Loughlin, 1988). Children's scientific reasoning skills, as well as their understanding of the nature of scientific knowledge, have been described as severely deficient, lacking the fundamental differentiation of theories and hypotheses from evidence (Kuhn, 2014; Kuhn & Franklin, 2006). This view is

* Corresponding author.
E-mail address: ozgun.tuncer@psy.lmu.de (Ö. Köksal-Tuncer).

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based on a large body of research on preadolescent children's hypothesis testing and evidence evaluation skills, indicating that children typically do not test hypotheses in a systematic way and often try to produce an effect rather than aiming at understanding its causes. Children often fail to control for confounding variables and they distort or ignore evidence if the data do not fit their prior beliefs (Kuhn et al., 1988).

However, recent research has shown that young children are far more skilled in scientific reasoning tasks than early studies claimed (Zimmerman, 2007). Elementary school age children differentiate hypotheses from evidence in preferring a conclusive over an inconclusive test for a hypothesis (Sodian, Zaitchik, & Carey, 1991), and a controlled over a confounded experiment (Bullock & Ziegler, 1999). They possess basic evidence evaluation skills (Masnick, Klahr, & Morris, 2007; Masnick & Morris, 2008; Piekny & Maehler, 2013; Saffran, Barchfeld, Sodian, & Alibali, 2016), and, by the age of about 10 years, some explicit understanding of the nature of science (Sodian, Thoermer, Kircher, Grygier, & Günther, 2002). Furthermore, there is evidence that the different components of scientific reasoning form a unitary construct and show regular progression during the elementary school years (Koerber, Mayer, Osterhaus, Schwippert, & Sodian, 2015).

There is far less evidence on scientific reasoning skills in early childhood. Croker and Buchanan (2011) studied the development of hypothesis testing strategies in a contextualized task in which children had strong prior beliefs. The plausibility of the hypothesis and outcome (good vs. bad) affected children's strategies at all ages. Even 4-year-olds chose an appropriate test strategy (manipulate one variable) when the evidence was consistent with their prior belief and the outcome was good or when the evidence was inconsistent with the prior belief and the outcome was bad. In contrast, when the evidence was inconsistent with the children's prior beliefs, children chose manipulations that were likely to lead to a positive outcome. Thus, it appears that young children did not firmly distinguish the goal of testing a hypothesis from the goal of producing a positive effect (or avoiding a negative one). Ruffman, Perner, Olson, and Doherty, (1993) showed that 6-year-olds understand that people's beliefs depend on the evidence available to them. They can predict that a character who saw a different pattern of evidence from *reality* would form a belief in accordance with the evidence they saw. Koerber, Sodian, Thoermer, and Nett, (2005) found competence in a similar task even in 4-year-olds, when the patterns of evidence were perfect or near-perfect covariation data. Thus, young children seem to possess a basic understanding of the role of data in belief formation, but it is unclear to what extent they can judge the quality and relevance of a specific piece of evidence.

The causal learning literature demonstrates that preschoolers can make accurate causal inferences from covariation evidence (Gopnik & Sobel, 2000; Schulz & Gopnik, 2004) and they also form cause–effect relations according to evidence even in the cases where causal relations are not in accordance with their prior beliefs (Kushnir & Gopnik, 2007; Schulz, Bonawitz, & Griffiths, 2007; Schulz, Kushnir, & Gopnik, 2007). These findings impressively document the systematic *use* of covariation evidence in causal learning. The *evaluation* of evidence, however, requires a *judgment* about the relevance or informativeness of a piece of evidence with respect to a hypothesis. Schulz and Bonawitz (2007) found that preschoolers preferentially explored toys for which they had received confounded evidence about the causal structure of the toy, rather than matched toys for which they had received unconfounded evidence, and they spontaneously disambiguated confounded variables in exploration, indicating that children maximize the new information to be gained from an exploration. While this method does not require explicit judgments of informativeness, the findings indicate some degree of *awareness* of the informativeness of the evidence with respect to an epistemic goal. Thus, an implicit awareness of the quality of evidence may developmentally precede explicit judgments. However, children may learn from informative evidence and selectively explore ambiguous evidence to maximize informativeness without understanding *what it is about evidence* that makes it informative or uninformative. To better describe young children's understanding of the quality of evidence, Cook, Goodman, and Schulz, (2011) investigated preschoolers' ability to distinguish between potentially informative and uninformative interventions. They provided children with either ambiguous or unambiguous evidence and investigated whether children would isolate variables to identify the cause of an effect. They found that children isolated variables selectively in the case of ambiguous evidence and they even invented novel ways to do so. These findings suggest that preschool children do not merely passively process covariation evidence to learn about cause–effect relations, but that they begin to use efficient strategies of active experimentation.

This conclusion is also supported by recent studies by Legare (2012) and Bonawitz, van Schijndel, Friel, and Schulz, (2012), which demonstrated that preschoolers are sensitive to inconsistent evidence. In both studies, preschoolers observed events which were inconsistent with their prior beliefs. Bonawitz et al. (2012) showed that preschoolers explored more when the evidence was inconsistent than when it was consistent with their prior beliefs. Furthermore, Legare (2012) showed that preschoolers' exploration behaviors were informed by their way of explaining inconsistent evidence. To illustrate, children who explained inconsistent evidence by referring to a malfunction of the object showed more hypothesis testing behaviors such as opening the inconsistent object or experimenting with object replacement than children who explained the inconsistent evidence by changing the category of the inconsistent object. Explanation prompts also support the search for hypotheses with a broad scope, based on prior knowledge or prior observations, as shown in 5-year-olds in a recent study by Walker, Lombrozo, Williams, Rafferty, and Gopnik, (2017).

The causal learning literature has generally studied exploratory play, rather than experimentation, which is typically investigated in the scientific reasoning literature. Conclusions from the observation of unconstrained exploration processes about the formation and testing of specific hypotheses are indirect and limited. In particular, children's tendency to maximize information in exploratory play does not imply that they will selectively generate informative (i.e., potentially disconfirming) evidence when testing a claim or when refuting a false claim. In the present study, we therefore aimed at directly assessing young children's scientific reasoning skills (hypothesis testing and counterargumentation skills) in a "blicket detector" paradigm (Gopnik & Sobel, 2000).

To gain direct evidence about young children's hypothesis testing skills, we need to ensure that they form a specific hypothesis about a cause–effect relation during an exploratory phase, which they can subsequently test on new materials. Therefore, in the