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Scientific reasoning in kindergarten: Cognitive factors in experimentation and evidence evaluation☆

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ABSTRACT

The aim of the present study was to investigate the role of cognitive factors in two core components of scientific reasoning: experimentation and evidence evaluation. Measures of visuospatial and verbal working memory, inhibition, cognitive flexibility, vocabulary, grammatical ability, and spatial visualization were related to experimentation and evidence evaluation results in 100 kindergartners. Using mediation analyses, results revealed that both inhibition and verbal working memory (as part of the executive functions) related indirectly to experimentation and evidence evaluation through grammatical ability, instead of through vocabulary. Visuospatial working memory did not relate to either components of scientific reasoning, and spatial visualization did not mediate the relation between executive functioning and scientific reasoning. The present results highlight the importance of verbal abilities in explaining individual differences in scientific reasoning in kindergarten.

1. Introduction

Science education involves both learning scientific concepts (i.e. content) and scientific reasoning (i.e. processes) (Klahr, Zimmerman, and Jirout, 2011). Focus in school-taught science has been on the content, where knowledge dominates reasoning (Osborne, 2013). Focus can be directed more towards scientific reasoning (Bricker and Bell, 2008). Scientific reasoning is conceptualized as the intentional seeking of knowledge through the application of scientific methods (Kuhn, 2004). It consists of three core components: hypothesis generation, experimentation, and evidence evaluation (Klahr, 2000; Klahr and Dunbar, 1988). Scientific reasoning is relevant for participation in the knowledge society as an autonomic, critical thinker and is a key part of so-called '21st century skills' (Fischer et al., 2014; Osborne, 2013). Scientific reasoning activities have already been receiving increased attention, as they are increasingly becoming part of science education standards (Next Generation Science Standards Lead States, 2013). In recent studies, individual differences in scientific reasoning have been investigated in primary school children (e.g. Mayer, Sodian, Koerber, and Schwippert, 2014; Wagensveld, Segers, Kleemans, and Verhoeven, 2014), but not in kindergarten, even though these individual differences can provide validations and/or implications for theories about scientific reasoning (e.g. Dunbar and Klahr, 2012). In addition, once it is known how children conduct scientific activities, they can be used to design teaching materials for science education. Scientific reasoning in kindergarten should receive more attention, because young children seem curious by nature (Engel, 2009) and they have been called "natural scientists" (Gopnik, 2012). Another advantage of kindergarten (i.e. children of four to six) is that it is at the very start of science education. This early experience can lead to more motivated and knowledgeable students of science, because (hands-on) experience with science can lead to greater interest and self-confidence in science (Ornstein, 2005). According to Piekny and Maehler (2013), kindergartners are able to evaluate evidence, but fail in the other two core components of scientific reasoning. However, Van der Graaf, Segers, and Verhoeven (2015) proved that kindergartners do have the ability for experimentation to a certain extent, as they were able to design unconfounded experiments with up to four variables. Therefore, in the present study, the focus was on cognitive factors explaining the variation in experimentation and evidence evaluation in kindergartners.

1.1. Scientific reasoning in kindergarten

The view of what kindergartners are capable of in terms of hypothesis generation, experimentation, and evidence evaluation as core components of scientific reasoning appears to have shifted from underestimation of their capabilities towards more recognition. Inhelder and Piaget (1958) revealed flaws in the logic of young children, such as the failure to distinguish between effects caused by their own

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actions and those caused by an external variable. Later research has revealed that young children have some scientific reasoning capabilities, but there is still debate on the exact potential of young children in scientific reasoning (Klahr et al., 2011). However, more recent studies revealed that kindergartners show at least partial understanding of scientific reasoning (Piekny and Maehler, 2013; Van der Graaf et al., 2015).

With respect to the generation of hypotheses, kindergartners have been shown to experience difficulties. When presented with accumulated evidence about which hypotheses can be generated, most kindergartners are able to develop only one correct hypothesis, whereas children at around 11 years of age show the ability to develop multiple hypotheses in accordance with the evidence presented (Piekny and Maehler, 2013). It appears that the generation process is difficult for young children, as well as understanding what a hypothesis is. While kindergartners often fail to set a dichotomous variable (i.e. small versus large door) to find out whether a small or a large mouse lives in the house, they fail to choose the small door. This is a test that produces conclusive evidence (Piekny and Maehler, 2013). When children are slightly older, i.e. 7 to 9 years old, they can generate a conclusive test, when asked to determine something (Sodian, Zaitchik, and Carey, 1991). When a hypothesis is given, these children were able to use the hypothesis to design a test. However, the generation part seems more difficult. It has been termed a search through hypothesis space (Klahr and Dunbar, 1988). Individuals search for observable features that support the generation of hypothesis and they attempt to develop mechanisms and models that account for the observed data (Schauble, 1996). It has been found that young children have extreme difficulty with this, as they tend to see themselves as causing an effect, rather than the variable under investigation (Inhelder and Piaget, 1958). Even when the correct observation has been made, the problem of confirmation bias still remains. Confirmation bias is a general human tendency to design experiments to confirm the favored hypothesis and ignore alternative hypotheses (Dunbar and Klahr, 2012). This makes the generation of hypotheses a difficult component of scientific reasoning.

With regard to experimentation, a critical variable concerns the Control of Variables Strategy (CVS) which is relevant for correctly designing experiments with multiple variables. CVS is about manipulating the variable in which one is interested, while keeping all other variables constant (Chen and Klahr, 1999). This way, something can be learned from the outcome of the experiment, since its design was unconfounded. Most kindergartners understand monovariable experiments when asked how to generate an effect (Piekny and Maehler, 2013) or predict the outcome of an experiment (Siegler and Chen, 1998), but have difficulties when the number of variables increases (Siegler and Chen, 1998). This effect has also been found in slightly older children (Chen and Klahr, 1999; Wilkening and Huber, 2004). However, it is important to take the task design into account. When dynamic assessment is used, kindergartners can design unconfounded experiments with up to four variables (Van der Graaf et al., 2015). This means that the children were given feedback based on their own performance, which is in line with the zone of proximal development proposed by Vygotsky (1978). Another approach to learn experimentation is through instruction, which is often contrasted with some type of discovery (or inquiry). Children aged 7 years old can already learn CVS from direct instruction, but this effect is small and short-lived (Chen and Klahr, 1999). In contrast, the 10 year olds in their study did show improved understanding of CVS after instruction, which stuck until transfer, one week later. When compared with self-discovery, direct instruction appears more effective, but all children (10 and 12 years old) improved their understanding of CVS, as shown by their design of multivariable experiments (Wagensveld et al., 2014). Experimentation also involves investigation of interacting variables, which is something that happens in daily-life. CVS cannot be used to investigate these interactions. The next step would be to develop multivariable thinkers (Kuhn, Ramsey, and Arvidsson, 2015). This is something in which even lay adults show less than optimal competency, but it is also something that students can learn during an intervention (Kuhn et al., 2015).

With reference to evidence evaluation, the critical issue is evaluating the evidence obtained after having conducted an experiment (Klahr, 2000). This evidence has to be evaluated correctly to draw the conclusion that fits the evidence. There are various kinds of evidence. Inconclusive evidence is evidence from which a conclusion cannot be drawn, given that half of the evidence contradicts the other half. For example, the conclusion that one cannot determine whether a certain color of chewing gums causes bad teeth, because two children with that color of chewing gum have bad teeth and two children with that color of chewing gum do not. This type of evidence is usually evaluated incorrectly by kindergartners (Piekny, Grube, and Maehler, 2014). Other kinds of evidence include conclusive and partial evidence. Conclusive evidence is evidence that irrefutably points to a single conclusion. Partial evidence provides a suggestion to what caused the effect, but it is not conclusive. It might be that 80% of the evidence points to the conclusion that red chewing gum causes bad teeth, while 20% of the evidence does not. Piekny et al. (2014) found that kindergartners can evaluate conclusive and partial evidence correctly, which indicates that they have a basic understanding of evidence evaluation. Their understanding can be improved with explicit feedback on their evaluation of evidence. When the experimenter explains why the child's conclusion was correct, kindergartners are better able to learn how to interpret inconclusive evidence correctly, compared to when no direct feedback is given (Klahr & Chen, 2003). Another aspect is pre-existing beliefs, which affect performance on evidence evaluation. The performance of kindergartners suffered when their prior beliefs conflicted with the data (Koerber, Sodian, Thoermer, and Nett, 2005).

1.2. Cognitive factors in scientific reasoning

Kindergartners, thus, show a basic understanding of experimentation and evidence evaluation. However, it is unknown which cognitive factors are able to explain the variation in scientific reasoning among kindergartners. Studies on older children show that verbal reasoning, vocabulary, and reading comprehension relate to scientific reasoning in 10- and 12-year-olds (Wagensveld et al., 2014), as well as inhibitory control, spatial abilities, and problem-solving skills in 10-year-olds (Mayer et al., 2014). In addition to these studies on individual differences, the memory model introduced by Baddeley (2000) will be used as a framework to select cognitive factors which can account for individual variation in kindergarten. The relevancy of the framework lies in the distinction between two main routes: a spatial and verbal route. The third route allows for the interaction between the two main routes. This third route is episodic and supports the integration and reflection of information (Baddeley, 2000). While the episodic route has been studied less extensively, there is clear evidence that the verbal and spatial route work independently (Baddeley, 2012). The routes are all controlled by the central executive. Information can be temporarily stored and manipulated at the working memory level. Information from working memory can be stored in and retrieved from the long-term memory. Broad categories of skills and knowledge are represented in long-term memory (Baddeley, 2012), including the skills and knowledge required for scientific reasoning.

With respect to working memory, three components can be identified, namely verbal and visuospatial working memory, and the central executive (Baddeley, 2000). The visuospatial sketchpad, referred to as visuospatial working memory, allows one to maintain and manipulate visual and spatial information. Visuospatial working memory has been shown to help kindergartners use mental models (Rasmussen and Bisanz, 2005). It has been proposed that kindergartners solve nonverbal problems using a mental model (Huttenlocher, Jordan, and Levine, 1994). Scientific reasoning is a problem-solving activity as well (Dunbar and Klahr, 2012), which could be done nonverbally. To solve problems, a mental model can be built with the relevant information.