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THEMENTEIL

Science competencies in kindergarten: a prospective study in the last year of kindergarten

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Abstract Science competencies are considered an important 21st century skill. How this skill develops in childhood is, however, not well understood, and in particular little is known about how different aspects of science competencies are related. In this prospective study with 58 children aged 5–6 years, we investigate the development of two aspects of science competence: scientific thinking and science content knowledge. Scientific thinking was assessed with a comprehensive 30-item instrument; science content knowledge was measured with an 18-item instrument that assesses children's knowledge with regard to melting and evaporation. The results revealed basic competencies in scientific thinking and science content knowledge at the end of kindergarten (46% and 49% correct, respectively, both different from chance). In mid-kindergarten, children performed better than chance on the assessment of science content knowledge (40% correct) but not on the assessment of scientific thinking (34% correct). Science content knowledge in mid-kindergarten predicted children's science content knowledge at the end of kindergarten, as well as scientific thinking (both at 6 years). The opposite pattern did not hold: scientific thinking in mid-kindergarten did not predict science content knowledge at the end of kindergarten. Our findings show initial science competencies during kindergarten, and they suggest that children's science content knowledge and scientific thinking are interrelated in a meaningful way. These results are discussed with respect to the different hypotheses that connect scientific thinking and science content knowledge

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as key features of science competencies. Implications for research and teaching are discussed.

Keywords Science competencies · Scientific thinking · Science content knowledge · Physics knowledge · Kindergarten

Wissenschaftliche Kompetenzen im Kindergarten: Eine prospektive Längsschnittstudie im letzten Kindergartenjahr

Zusammenfassung Wissenschaftliche Kompetenzen werden als Schlüsselqualifikation im 21. Jahrhundert betrachtet. Wie sich diese Kompetenz in der Kindheit entwickelt, ist jedoch nicht hinreichend untersucht und so ist bis dato wenig bekannt über die Beziehung zwischen zentralen Aspekten wissenschaftlicher Kompetenz. In dieser prospektiven Studie mit 58 fünf- bis sechsjährigen Kindergartenkindern haben wir die Entwicklung von zwei zentralen Aspekten wissenschaftlicher Kompetenzen untersucht: dem wissenschaftlichen Denken und naturwissenschaftlichen Inhaltswissen. Wissenschaftliches Denken wurde mit einem umfassenden Instrument mit 30 Items erfasst; naturwissenschaftliches Inhaltswissen mit einem Instrument mit 18 Items, die das Verständnis der Kinder zu den Konzepten Schmelzen und Verdunstung erfassen. Die Ergebnisse zeigten Basiskompetenzen am Ende des Kindergartens – sowohl im wissenschaftlichen Denken als auch im naturwissenschaftlichen Inhaltswissen (46 % bzw. 49 % korrekt; beide signifikant besser als Ratewahrscheinlichkeit). Während des ersten Messzeitpunkts (mittleres Kindergartenalter) war die Leistung im naturwissenschaftlichen Inhaltswissen (40 % korrekt), jedoch nicht die im wissenschaftlichen Denken (34 % korrekt) signifikant besser als per Zufall erwartet. Das naturwissenschaftliche Inhaltswissen der Kinder im mittleren Kindergartenalter sagte das naturwissenschaftliche Inhaltswissen und das wissenschaftliche Denken am Ende des Kindergartens voraus (beide mit 6 Jahren). Umgekehrt war dies nicht der Fall: Wissenschaftliches Denken mit 5 Jahren sagte nicht das naturwissenschaftliche Inhaltswissen mit 6 Jahren voraus. Unsere Befunde zeigen beginnende wissenschaftliche Kompetenzen im Kindergartenalter, die verschiedene Bereiche umfassen. Zudem deuten unsere Ergebnisse darauf hin, dass naturwissenschaftliches Inhaltswissen und wissenschaftliches Denken bedeutungsvoll miteinander verknüpft sind. Diese Ergebnisse werden in Hinblick auf verschiedene Hypothesen zum Zusammenhang zwischen wissenschaftlichem Denken und naturwissenschaftlichem Inhaltswissen diskutiert, ebenso wie Implikationen für Wissenschaft und Unterricht.

Schlüsselwörter Wissenschaftliche Kompetenzen · Wissenschaftliches Denken · Naturwissenschaftliches Inhaltswissen · Physikverständnis · Kindergarten

1 Introduction

Science competencies comprise two key aspects: scientific thinking and science content knowledge (OECD 2010). Although policy makers and school science standards (e.g., NRC 2012) stress the importance of promoting science competencies already before children enter formal schooling, kindergarten classrooms do not coherently and consistently foster the development of such skills (Gopnik 2012). There are only few examples of kindergarten science curricula that have been implemented (e.g., Preschool Pathways to Science, Science Start, see also the Initiative Haus der kleinen Forscher), and robust evaluations are still scarce (Greenfield et al. 2009; Klahr et al. 2011; Pahnke and Pauen 2014).

Although there is now a growing body of research that shows basic competencies in kindergarten in both scientific thinking and science content knowledge (e.g., Wilkening and Cacchione 2011; Zimmerman 2007), researchers are just now beginning to investigate how science competencies develop and how the two aspects of early science competencies (i.e., scientific thinking and science content knowledge) may be related.

In this study, we investigate the development of science competencies in the last year of preschool (i.e., in the kindergarten year), asking if science content knowledge (i.e., knowledge about particular scientific phenomena) and scientific thinking (i.e., mastery of the reasoning processes involved in science) are interrelated. The study contributes to the literature by using a two-point measurement, prospective design that allows to determine the pattern and direction of the interrelation.

2 Scientific thinking and science content knowledge

Scientific thinking and science content knowledge are considered two key aspects of science competencies. Although different terms and taxonomies exist in the literature, most authors differentiate content components (e.g., domain-specific knowledge) from process components (e.g., reasoning and strategies of knowledge acquisition, such as experimentation or evidence-evaluation strategies) (Bybee 1997; Klahr et al. 2011; OECD 2010). In this study, we follow Anders et al. (2018a) and Hardy et al. (2010) who distinguish between domain-specific content knowledge (i.e., knowledge about specific scientific phenomena; here: science content knowledge) and domain-general process knowledge (i.e., knowledge of scientific processes and methods, as well as a metaconceptual understanding of these processes; here: scientific thinking, see also Koerber and Osterhaus 2019).

Scientific thinking is defined as intentional knowledge seeking (Kuhn 2002) and it comprises various subskills, including the abilities to come up with explanations for phenomena that children observe in their environments, to generate suitable hypotheses, to test them, and to interpret the evidence (for a review, see Zimmerman 2007). Because all these activities are genuine science activities, and because they allow to test existing beliefs and to generate new knowledge, scientific thinking plays an important role in schools, where it is considered an important outcome of science education (e.g., NRC 2012). In modern knowledge societies, scientific thinking is a key competence that people need to develop in order to actively participate in public debates and discourse (e.g., Fischer et al. 2014).

Developmental research traditionally assumed that children's scientific thinking would not develop before secondary school when children begin to master formal operational thought (e.g., Inhelder and Piaget 1958). A growing body of research, however, has revealed basic scientific-thinking competencies in children as young as elementary school (e.g., Koerber et al. 2015; Osterhaus et al. 2017, 2020; Sodian et al. 1991) and even preschool age (Piekny and Maehler 2013). These basic skills include the abilities to generate disconfirming evidence, to understand the basic processes of knowledge construction, and to differentiate a good from a bad experiment: For instance, 3- to 6-year-old children generate disconfirming evidence when they are presented with a false causal claim (Köksal-Tuncer and Sodian 2018). Kindergarteners also understand that science is about asking questions and finding explanations (i.e., they understand the nature of science; Samarapungavan et al. 2009), and 4- and 6-year-olds can differentiate between a confounded and an unconfounded experiment (van der Graaf et al. 2018).

Science content knowledge is defined as knowledge about scientific phenomena across various domains, including for instance physics, biology, and chemistry (e.g., OECD 2010). There is a consensus that young children possess a fair amount of science content knowledge long before they enter formal schooling, which they acquire through active exploration and everyday experiences with natural phenomena (e.g., Wilkening and Cacchione 2011), often in interaction with more competent peers and adults. Through these explorations and experiences, children build subjective, intuitive theories (e.g., Vosniadou 2009). These may be similar to those of an adult (especially when the domain or topic is easily accessible to the child through exploration). Often, however, children's intuitive theories are marked by misconceptions and a lack of differentiation (e.g., Vosniadou and Brewer 1992). One prominent example is children's developing theory of the earth, which undergoes a process of reconstruction from a (naïve) representation of the earth as a flat disc (misconception) to the geospheric model of the earth. Similarly, in the domain of floating and sinking, preschool children usually do not yet display an advanced understanding of density and its effects on floating and sinking. They therefore often expect that a large wooden block would sink while a small iron needle would float, thus focusing on salient features such as size or weight (Leuchter et al. 2014). Entertaining misconceptions about a particular phenomenon may guide the way that children further explore science domains. When children hold strong naïve theories, they may be more likely to ignore evidence that is not in line with their theories. This may result in interferences with scientific-thinking processes, which may be particularly strong in children with less pronounced scientific-thinking skills.

According to Anders et al. (2018b), children's self-directed explorations of science topics are "foundational experiences", which serve as the basis for the "structured experiences" that are shaped by more competent adults. These structured experiences allow children to draw comparisons between different situations (e.g., different aspects of the same phenomena), thus providing them with the relevant situations that allow them to deliberately reflect upon these phenomena and compare them across situations. In the domain of melting and evaporation, a foundational experience refers, for instance, to a child playing with water; a structured experience, in turn, refers to a situation in which an adult prompts a child to let an ice cube melt in their hand, mouth, or in a drink (Anders et al., 2018b; Steffensky et al. 2012). Such structured experiences and scaffoldings are pivotal for children to develop more mature conceptions of natural science phenomena. Kloos and Van Orden (2005), for instance, showed that 4- to 6-year-old children correctly use evidence (here, specifically designed demonstrations) to revise their prior incorrect beliefs about scientific phenomena (here, about the predictors of sinking speed) when presented with relevant evidence in a structured instructional environment.

Research in kindergarten has shown that scientific thinking and science content knowledge are two constructs that are distinct, yet interrelated, with a significant independent correlation of around $\rho = 0.39$ (i.e., independent from the influence of general cognitive abilities) (Koerber and Osterhaus 2019). It is worth noting that the correlation between science content knowledge and scientific thinking was substantially higher than the one between scientific thinking and mathematics (Koerber and Osterhaus 2019), suggesting that there is a functional relation between the two constructs. However, it is hitherto not well understood whether this relation is a bidirectional one—or whether mature scientific thinking leads to advanced science content knowledge, or vice versa. There are three ways in which scientific thinking and science content knowledge may be related:

2.1 Scientific thinking promotes the acquisition of science content knowledge (hypothesis 1)

Hypothesis 1 states that people use their scientific-thinking skills to acquire new content knowledge. In particular, this hypothesis assumes that people will be more likely to test their naïve explanations of scientific phenomena once they understand that assumptions have to be tested, and they know how to test these assumptions (e.g., by conducting an experiment and by interpreting the result of this everyday experiment). Consider, for instance, a group of elementary school children who—either solitary or in an especially constructed learning environment—explore the variables that determine if an object floats or sinks. The children who know and understand that they need to test their assumptions and who know the relevant strategies to do so, will be more likely to test and revise their naïve conceptions. For instance, the children who are skillful in scientific thinking will presumably be more likely to test the incorrect assumption that weight is the only variable that affects whether or not an object floats. Accordingly, these children will, once they conducted their experiment, be more receptive to explanations given by adults (e.g., teachers) and they will be more likely to conceive of density as the relevant variable instead of weight. This way, the children will likely acquire advanced science content knowledge.

Empirical evidence in support of this assumption comes from the finding that elementary school children with high experimentation skills are more likely to restructure their physics knowledge during inquiry-based physics units than are children with lower experimentation skills (Edelsbrunner et al. 2018; see also Driver et al. 1996, Songer and Linn 1991). In particular, Edelsbrunner and his colleagues (2018) presented 1st–6th graders with 15 lessons on floating and sinking in a classroom setting. Scientific thinking was operationalized as experimentation skills, which were measured by assessing children's mastery of the control of variables strategy (CVS). CVS holds that an informative experiment should only vary one variable at a time while keeping all others constant. Edelsbrunner et al. (2018) found that children's initial mastery of CVS was correlated with their science content knowledge (here: floating and sinking), and more importantly, mastery of CVS predicted the increase in conceptual understanding after 15 lessons. In particular, those students with high CVS skills were more likely to restructure their science content knowledge, revealing more advanced knowledge and fewer misconceptions in the posttests. These findings from elementary school are in line with findings from secondary school where a broad set of scientific-thinking skills has been found to predict students' science content learning in biology between grades 6 and 8 (Cannady et al. 2019).

2.2 Science content knowledge enables students to think scientifically (hypothesis 2)

Hypothesis 2 states that science content knowledge helps people to engage in skillful scientific thinking. Skillful scientific thinking requires that people identify the key features and variables of the science problem at hand. For instance, in floating and sinking, some basic content knowledge is required for individuals to identify the relevant candidate causes that affect whether or not an object floats. Thus, one may assume that children need a basic conceptual knowledge on mass, volume, and material kind in order to isolate, manipulate, and further investigate these variables in their experiments (see Leuchter et al. 2014). Science content knowledge is thus relevant for guiding individuals' attention to critical features of a situation or problem. Only when people know what kind of information they need to pay attention to, can they more readily encode this critical information, allowing them to process and represent it in an effective way. Generally, encoding and representing the problem in an effective way are considered important prerequisites that facilitate reasoning and that are conducive to more sophisticated scientific thinking (Morris et al. 2012).

Empirical evidence for the hypothesis that science content knowledge promotes scientific thinking is limited, and this question has mostly been addressed in studies involving older students (i.e., high school and college students). A study by Schwichow et al. (2020) found that secondary school students' science content knowledge is associated with their experimentation skills in the same domain. In particular, the authors found that students with advanced science content knowledge with regard to "heat and temperature," and "electricity and electromagnetism" are more skillful in applying CVS to problems in the same domains than are students with less pronounced science content knowledge.

There is, however, also evidence that suggests that science content knowledge may be of little relevance for students' scientific-thinking skills: Bao et al. (2009) found no difference in scientific-thinking skills between a sample of Chinese and US college students. However, while the Chinese students had undergone a rigorous content-rich STEM education in school, the US college students had not received such rigorous STEM education. This suggests that science content knowledge may be less relevant to the development of scientific-thinking skills than presumed.

2.3 Scientific thinking and science content knowledge are related in a bidirectional manner (hypothesis 3)

Hypothesis 3 states that there are bidirectional associations between scientific thinking and science content knowledge. This hypothesis is in line with the former two hypotheses, and it assumes that both explanations hold.

Hitherto, there is little empirical evidence that supports either of the three hypotheses, except for a study by van der Graaf et al. (2018): Van der Graaf investigated the interrelations between scientific thinking and science content knowledge in a prospective study in kindergarten. Scientific thinking was assessed with a task that measures children's ability to interpret simple patterns of covariation data (evidence evaluation task, see Koerber et al. 2005) and a task that measures their mastery of the control of variables strategy (an adaptation of a CVS task by Chen and Klahr 1999). Science content knowledge was assessed with 40 tasks from four content domains (plants and growth, floating and sinking, sun and shadows, and paper planes). The results showed that evidence-evaluation skills (but not experimentation skills) in mid-kindergarten predicted science content knowledge at the end of kindergarten. Van der Graaf and his colleagues (2018) interpret this finding as being supportive of Hypothesis 1 (scientific thinking promotes the acquisition of science content knowledge). However, their findings also showed that science content knowledge in mid-kindergarten predicts both evidence evaluation and experimentation skills at the end of kindergarten. Taken together, this pattern of results seems to support the hypothesis that the relation between scientific thinking and science content knowledge is not unidirectional, but indeed bidirectional (Hypothesis 3).

Science competencies (both scientific thinking and science content knowledge) have been associated with children's general cognitive development (e.g., Bauer and Booth 2019; Koerber and Osterhaus 2019; van der Graaf et al. 2016), which may lead to spurious correlations. Studies of the interrelation between scientific thinking and science content knowledge must therefore consider the common influence of general cognitive development, and in particular of intelligence (Mayer et al. 2014) and language skills (Koerber and Osterhaus 2019), which have been identified as two important correlates of scientific thinking and science content knowledge.

To address the relation between scientific thinking and science content knowledge and to investigate the direction of the association, prospective studies with at least two points of measurement are needed. While previous cross-sectional studies provided some data on the relation between both factors of science competencies in school age, little is known about children's early science competencies in kindergarten and the early (co-)development of scientific thinking and science content knowledge (but see van der Graaf et al. 2018).

3 The present study

The goal of the present prospective study is to investigate the strength and direction of the association between scientific thinking and science content knowledge during the last year of kindergarten (i.e., before children enter formal schooling). In addition, our study investigates children's performance and the stability of individual differences in science competencies. Based on the literature on pre- and elementary school science competencies (e.g., Koerber and Osterhaus 2019; van der Graaf et al. 2018), we hypothesized that both aspects of science competencies (i.e., scientific thinking and science content knowledge) are related, that this relation is independent from the common influence of general cognitive abilities, and that this relation is bidirectional (Hypothesis 3). To address these questions, we measured children's scientific thinking and their science content knowledge at two measurement points (at the beginning and at end of the last year of kindergarten), and we used correlational and regression analyses to investigate the associations between the constructs. For testing science content knowledge, we chose the concept of melting and evaporation which has been widely investigated and for which basic competencies were found in preschool (Carstensen et al. 2011; Steffensky et al. 2012).

4 Method

4.1 Participants

In total, $N = 58$ children (31 girls, 27 boys) participated in this prospective study with two measurement points during the last year of kindergarten: one at the beginning of the last year of kindergarten in fall 2014 (we refer to this as "mid-kindergarten" and "5-year-olds") and one at the end of kindergarten in early summer 2015 (we refer to this as "end of kindergarten" and "6-year-olds"). The average time between the two measurement points was approximately 7 months (roughly representing the time between the beginning and end of the kindergarten year in fall and spring/summer). In mid-kindergarten, the mean age of the children was 5 years 7 months ($SD = 3.72$ months); at the end of kindergarten, it was 6 years 2 months ($SD = 3.53$ months). Eight of the 58 children (13.97%) spoke at least one language other than German at home.

The sample was a convenience sample. The children attended six mostly middle-class kindergartens close to a mid-sized city in southern Germany. All children who agreed to take part in a longitudinal study were selected. Child assent and written consent from caretakers were obtained for all participants. Institutional review board (IRB) approval was not sought for the study because the host institution [PH Freiburg] did not have an established IRB. Due to days of illness or longer leaves not all of the children participated during all days of assessment. Measures of scientific thinking were obtained from all children, as was science content knowledge at the end of kindergarten. In mid-kindergarten, science content knowledge was assessed from 42 children. Part of the children included in this study continued—together with another cohort—in an ongoing longitudinal study.

4.2 Materials

4.2.1 Scientific thinking

Scientific thinking was assessed with a 30-items inventory (Koerber and Osterhaus 2019). The Science-K inventory is a comprehensive assessment of children's scientific-thinking abilities, including their skills in experimentation, data interpretation, and understanding the nature of science (NOS). For each item, the children are presented verbally and visually with a short story (one to three sentences), which is followed by the test question. For each test question, three answer options are given, with only one alternative being correct (i.e., the probability of answering correctly by chance is 33.3%).

Experimentation Ten experimentation items assess children's ability to distinguish between testing hypotheses and producing effects and their understanding of CVS. In one item, for instance, the children are asked how one could find out whether a person is good at doing puzzles. Three answer options are offered: one should ask this person to put together (a) their favorite puzzle, (b) a puzzle with few pieces, or (c) a puzzle with many pieces (correct).

Data interpretation Data-interpretation skills were tested with six items that assess children's interpretation of data patterns of covariation data and with four items that assess children's understanding of confounded data. For example, one item presents children with a story about a protagonist who holds the hypothesis that having new running shorts makes someone run fast. The children are then presented with data: "Mia runs fast when she is wearing her new shorts and new shoes; and she runs slow when she is wearing her old shorts and her old shoes". The children are asked to evaluate the data and to decide whether Mia is running fast (a) "because of her new shorts," (b) "because of her new shoes," or whether (c) "it cannot be determined whether it was because of her new shorts or her new shoes" (correct).

Nature of science (NOS) Ten NOS items asked the children questions about science and scientists. One item, for instance, asked the children to pick an example of someone who is doing science: (a) Anna—who wonders why mixing yellow and blue gives green (correct); (b) Lea—who watches her father mix colors; or (c) Mia—who helps her dad paint the wall. Another item asked the children to pick an example of the type of questions that scientists ask. For all questions, the children are given three answer options from which they have to choose the best one.

The reliability of the full instrument was good with Cronbach's $\alpha = 0.70$ in mid-kindergarten ($n = 58$), and Cronbach's $\alpha = 0.66$ at the end of kindergarten ($n = 58$). The internal consistency of the instrument is good, with Cronbach's $\alpha = 0.78$. Rasch analysis showed that the 30 items fit a unidimensional model (Koerber and Osterhaus 2019). The inventory can be retrieved from Open Science Framework: (https://osf.io/38yn5/).

4.2.2 Science content knowledge (melting and evaporation)

Science content knowledge was measured with 18 items that assessed children's understanding of melting and evaporation. These items were adapted from the SnAKe project (Carstensen et al. 2011; Steffensky et al. 2012) to match the format of the scientific-thinking inventory (i.e., each item was visually displayed and three answer options were given, again resulting in chance of correct responding of 33.3%). One of the science content knowledge test items, for instance, asked the children to select an answer on how one can find out whether a gummi bear melts: (a) you put it onto a warm radiator (correct), (b) you put it into cold water, or (c) you put it into a dark room. The reliability of the scale was good with Cronbach's $\alpha = 0.74$ in mid-kindergarten ($n = 42$), and Cronbach's $\alpha = 0.66$ at the end of kindergarten ($n = 58$).

4.2.3 General cognitive abilities (control)

To control for children's general cognitive development, we assessed their intelligence and their language skills at the end of the kindergarten.

Intelligence was assessed with ten items from the subtest logical reasoning of the Vienna Development Test (Kastner-Koller and Deimann 1998). The children had to choose one of five items that completes a series of 3×3 matrices (comprising color, form, and size) (Cronbach's $\alpha = 0.86$).

Language abilities were measured with 12 items from the subtest "language receptive" of the Intelligence and Developmental Scales (Grob et al. 2009). In this test, the children were asked to replay spoken sentences with increasing grammatical complexity using toy figures (Cronbach's $\alpha = 0.76$).

4.3 Procedure

All assessments were conducted in quiet, separate rooms at the children's kindergarten institutions. The interviews were carried out by trained researchers, and they comprised five individual one-on-one sessions at each point of the measurement (mid- and end of kindergarten). All interviews were standardized with written-out protocol. Scientific thinking was assessed in the first three sessions, followed by the assessments of children's general cognitive abilities and their science content knowledge. Each testing session lasted approximately 20 min.

4.4 Coding and statistical analyses

For the scientific-thinking inventory and the assessment of science content knowledge, the maximum score to be obtained was 30 and 18 points, respectively (one point was given for each correct answer). In order to more easily compare performance across measures, core performance was transformed to the mean percentage correct. Missing data for $n = 16$ children for science content knowledge (during mid-kindergarten) were not imputed.

The results section first reports on children's core performance at both times of measurement and tests it against answering by chance. Thereafter, we report the findings of a repeated-measures analysis of variance (ANOVA) that asks if there was significant development in scientific thinking and in science content knowledge from 5–6 years. Finally, we report the bivariate correlations and the cross-lagged (partial) correlations in order to test our hypotheses regarding the patterns of independent associations between scientific thinking and science content knowledge (controlling for intelligence and language abilities).

5 Results

5.1 Core performance and development: science competencies at age 5 and 6

At 5 years, we found a mean of 33.79% correct ($SD = 14.29$) on the scientific-thinking items and a mean of 40.01% correct ($SD = 19.48$) on the science content-knowledge items (Fig. 1). The mean performance on the measure of scientific thinking did not differ significantly from what would be expected by chance (33.3% correct), t (58) = 0.36, $p = 0.717$; for science content knowledge, performance was significantly better than chance, t (41) = 2.33, $p = 0.025$, and it was marginally higher than the children's performance on the scientific-thinking assessment, t (41) = 2.00, $p = 0.055$.

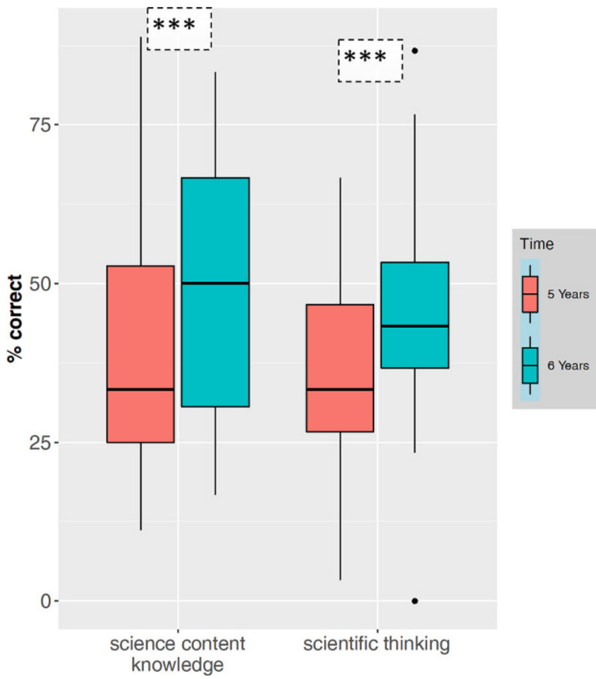

Fig. 1 Box-plot showing children's performance in science content knowledge and scientific thinking, at 5 and 6 years (*Lower* and *upper box* boundaries show 25th and 75th percentiles, respectively. The *line inside the box* shows the median, lower and upper error lines are 10th and 90th percentiles, respectively. The *black circles* show data falling outside 10th and 90th percentiles. *** $p < 0.001$)

At 6 years, the average percent correct was 46.26% ($SD = 13.95\%$) for scientific thinking, and it was 48.95% ($SD = 18.59$) for science content knowledge. Both average percentages differed significantly from the average that would be expected by chance: t (57) = 7.24, $p < 0.001$, and t (57) = 6.53, $p < 0.001$, for scientific thinking and science content knowledge, respectively. There was no significant difference between children's performance on the measures of scientific thinking and the science content knowledge, t (57) = 1.14, $p = 0.258$.

A repeated-measures analysis of variance revealed a significant main effect of time for children's scientific thinking and science content knowledge (Wilk's $\lambda = 0.54$, F (1, 41) = 34.68, $p < 0.001$, partial $\eta^2 = 0.458$). There was, however, no significant main effect of construct (i.e., scientific thinking vs. science content knowledge) (Wilk's $\lambda = 0.92$, F (1, 41) = 3.39, $p = 0.073$), as well as no interaction between time and construct (Wilk's $\lambda = 0.97$, F (1, 41) = 1.26, $p = 0.268$). Two separate, follow-up repeated-measures ANOVAs showed that there was a significant increase in both scientific thinking (Wilk's $\lambda = 0.63$, F (1, 57) = 33.22, $p < 0.001$) and science content knowledge (Wilk's $\lambda = 0.97$, F (1, 41) = 12.88, $p = 0.001$).

5.2 Relations between scientific thinking and science content knowledge

The correlations between children's scientific thinking and their science content knowledge, as well as the associations with children's general cognitive abilities (intelligence and language skills) are provided in Table 1. The data show moderate stability between 5 and 6 years in children's scientific thinking ($r = 0.32$, $p = 0.015$) and their science content knowledge ($r = 0.65$, $p < 0.001$). The concurrent association between scientific thinking and science content knowledge was more pronounced at 6 years ($r = 0.43$, $p = 0.001$) than at 5 years ($r = 0.34$, $p < 0.029$). Language skills were related to both scientific thinking and science content knowledge; intelligence correlated with scientific thinking at 6 years (but not 5 years), and with science content knowledge at 5 years (but not 6 years; see Table 1).

The cross-lagged (partial) correlations are provided in Fig. 2. Controlling for children's intelligence and language abilities, the autocorrelation between scientific thinking at 5 and 6 years was not significant ($r = 0.27$, ns), which may be due to

Table 1 Correlations Between Scientific Thinking, Science Content Knowledge, and Cognitive Control Variables

	Scientific thinking		Science content knowledge	
	5 years	6 years	5 years	6 years
Scientific thinking				
5 years	–	0.32*	0.34*	0.23#
6 years	–	–	0.50*	0.43**
Science content knowledge				
5 years	–	–	–	0.65***
6 years	–	–	–	–
Language (6 years)	0.30*	0.36**	0.46**	0.30*
Intelligence (6 years)	0.11	0.27*	0.35*	0.21

# $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

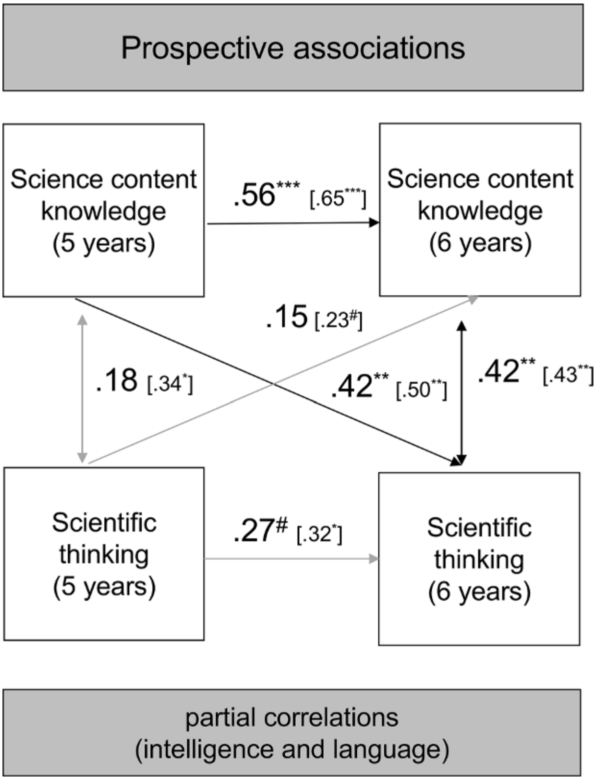

Fig. 2 Cross-lagged partial correlations between children's performance in science content knowledge and scientific thinking at 5 and 6 years, with intelligence and language controlled for (Bivariate correlations (without controlling for language and intelligence) are given in brackets. # $p<0.1$; ** $p<0.01$; *** $p<0.001$)

the floor effect that we found for scientific thinking at 5 years (i.e., performance did not differ from chance). There was a significant cross-lagged correlation between science content knowledge (at 5 years) and scientific thinking (at 6 years; $r=0.42$, $p<0.01$)—the reverse pattern did, however, not hold: there was no significant cross-lagged association between scientific thinking (at 5 years) and science content knowledge (at 6 years; $r=0.15$, ns).

To investigate how much variance in scientific thinking at 6 years was explained by science content knowledge at 5 years, we computed the partial correlation between these two measures, controlling for children's scientific thinking at 5 years. This partial correlation between science content knowledge at 5 years and scientific thinking at 6 years was $\rho=0.43$, $p=0.005$ (95% confidence interval between 0.17 and 0.61), suggesting that high science content knowledge in mid-kindergarten may result in higher scientific thinking at the end of kindergarten. The reverse pattern did not hold. The partial correlation between scientific thinking at 5 years and science content knowledge at 6 years (controlling for science content knowledge at 5 years) was nonsignificant, $\rho=0.08$, $p=0.637$ (95% confidence interval between –0.28 and 0.39), suggesting that profound scientific-thinking skills in mid-kindergarten may not result in greater science content knowledge at the end of kindergarten. It is worth noting, however, that the confidence intervals of the two correlations overlap, making it impossible to conclude with certainty that the two correlations did indeed differ significantly.

Finally, we tested whether children's scientific thinking at age 5 predicts their gains in science content knowledge from age 5 to age 6 (i.e., the difference between children's science content knowledge at age 6 and age 5). No significant correlations emerged between this score and children's scientific thinking at 5 years (r=–0.10, p=0.502), their intelligence (r=–0.12, p=0.449), or language abilities (r=–0.19, p=0.231). There was a negative correlation between children's gains and their science content knowledge at 5 years (r=–0.49, p=0.001) showing that low science content knowledge in mid-kindergarten led to greater gains in science content knowledge at the end of kindergarten.

6 Discussion

Is there a relation between scientific thinking and science content knowledge in early science competencies? And how do individual differences in science competence develop during the last year of kindergarten? These two main questions were addressed in the present study.

6.1 The relation between scientific thinking and science content knowledge

Scientific thinking and science content knowledge are two aspects of science competencies, and our results show that they are related. In particular, we found that science content knowledge in mid-kindergarten predicted children's scientific thinking at the end of kindergarten. The reverse pattern did not hold: Scientific thinking in mid-kindergarten did not predict science content knowledge at the end of kindergarten. Also, there was no relation between children's gains in science content knowledge and their scientific thinking. This finding did not follow our expectation, and we provide two interpretations:

First, it may well be that scientific thinking does, indeed, not predict kindergarten children's acquisition of science content knowledge (Hypothesis 1). It seems reasonable to assume that children do not display a high degree of content knowledge on scientific phenomena. Basic knowledge on these phenomena may, however, be necessary before children can draw abstractions, infer a general strategy on how to proceed when investigating phenomena, and interpret respective results. This would suggest that Hypothesis 2 (science content knowledge enables children to think scientifically) is correct.

Second, and this is an alternative interpretation, there may be two methodological reasons for this null finding. On the one hand, it may well be that we did not find a significant relation between scientific thinking and science content knowledge because of the content domain that we chose (i.e., knowledge on melting and evaporation). Evaporation is a topic that allows for much less experimentation and direct perception (Tytler 2000) than do other kindergarten and elementary school science topics. For example, the topic of floating and sinking, if used in instructional environments (see Leuchter et al. 2014; van Schaik et al. 2020), allows for the manipulation of objects and direct perception of effects. On the other hand, it may well be that the null finding arose because of the floor effect in scientific thinking in mid-kindergarten: At 5 years, the children revealed relatively low skills in scientific thinking, not different from chance. This interpretation is in line with findings by van der Graaf et al. (2018), who found significant links between science content knowledge and scientific thinking for simple but not for difficult aspects of scientific thinking (i.e., associations emerged for data interpretation but not for experimentation). If this interpretation is correct, then most likely bidirectional relations exist between scientific thinking and science content knowledge (Hypothesis 3).

The idea that there are bidirectional relations between scientific thinking and science content knowledge receives some support from the literature. Van der Graaf et al. (2018) found that science content knowledge significantly predicted scientific thinking (experimentation, evidence evaluation) from mid to late kindergarten, and that scientific thinking (evidence evaluation) predicted science content knowledge. Together with the present findings, this evidence seems to suggest that science content knowledge contributes to children's scientific thinking: In particular, it seems plausible that having built some initial understanding by exposure to basic experiences with natural sciences helps children to identify relevant variables and to encode the structure of a given situation, thus supporting them in thinking and reasoning scientifically.

6.2 The development of scientific thinking and science content knowledge during the last year of kindergarten

Basic abilities in scientific thinking emerge at the end of kindergarten (e.g., Butler 2020; Klahr et al. 2011). In particular, previous studies have documented emerging scientific-thinking skills at the end of kindergarten both in single aspects of scientific thinking (e.g., see Koerber et al. 2005; Köksal-Tuncer and Sodian 2018; van der Graaf et al. 2018) and across a broader set of skills (i.e., mastery of different experimentation skills, understanding the nature of science, and data-interpretation skills, Koerber and Osterhaus 2019). The novel finding of the present study is that the end of kindergarten seems to be exactly the time when these basic abilities first emerge across a broad range of skills: The performance of the 5-year-old children in our study did not exceed chance level. This suggests that, indeed, broad scientific thinking skills first emerge around the age of 6 years, which is a finding that is in line with recent studies linking scientific thinking to the development of metacognition, theory of mind, and self-regulation (Fridman et al. 2020; Osterhaus et al. 2017; Weinstock et al. 2020).

In contrast, basic abilities in science content knowledge (here: melting and evaporation) were already present at 5 years (in mid-kindergarten) and the children showed significant gains at the end of kindergarten. This is in line with previous studies that find basic but fragile science content knowledge across a wide range of scientific phenomena (e.g., Wilkening and Cacchione 2011). Although the present study did not assess the development of different levels of (mis)conceptions, our results support the hypothesis that kindergarten is an important period during which children develop and construct science content knowledge.

6.3 Limitations

The present study is one of few prospective studies of science competencies in kindergarten. Prospective studies are important because they allow to draw conclusions about the direction of associations; however, due to their limited number of measurement points, conclusions must be drawn with caution. In order to thoroughly investigate the direction, paths, and stability of the associations between scientific thinking and science content knowledge, more measurement and true longitudinal studies are needed. Our ongoing project Science K(indergarten) follows kindergarten children throughout elementary and until middle school, using gradually more difficult scientific-thinking tasks (see Nyberg et al. 2020). Once completed, this study will help us to better understand the (co-)development of scientific thinking and science content knowledge.

Science content knowledge was, in the present study, assessed in a science domain of early physics. We chose the topic of melting and evaporation because research shows initial competencies in this domain, and additionally, a well-researched instrument was available for this age group (Steffensky et al. 2012). Children's science content knowledge, however, differs across different topics and domains (see also Pollmeier et al. 2017), and for this reason, it may well be that our results would have been different with another science topic. Future research needs to address this question and would at best assess a broader range of science content knowledge, ideally across different science domains.

The children that participated in the present study were a convenience sample. While this limits the generalizability of our findings, it is worth noting that our results are in line with the emerging scientific-thinking skills in kindergarten reported in the literature. Indeed, many studies find initial competencies in some, but not all children, that—in children of preschool age—often depend on the specific nature of the task and may not translate across contexts (Weisberg et al. 2020). Therefore, we believe that it is important to assess scientific thinking in a comprehensive manner. This interpretation is also supported by findings that show the large variation in solution rates for similar items included in the inventory of scientific thinking employed in this study (Koerber and Osterhaus 2019).

In the present study, we asked how closely scientific thinking and science content knowledge are related in the last year of kindergarten. Our findings support the hypothesis that meaningful relations exist between the two constructs. Yet, more refined studies are needed to shed light on the precise nature of this relation. In particular, future research should investigate whether children's science activities (in kindergarten and at home) determine the strength of this relation. It is reasonable to assume that the association is stronger in children who frequently engage in science activities with their peers, caretakers, or educators. Recent studies show that the quality of these interactions determines the scientific-thinking processes of young children (Sobel et al. 2020), with adults' prior science knowledge being an important determinant of how children act in situations of inquiry (Franse et al. 2020). Because children acquire novel science content knowledge first and foremost in situations that are structured by parents or teachers, the teaching of science content knowledge is an important aspect of K-12 teacher education.

6.4 Implications

In the last years, large efforts have been made to implement scientific literacy education in elementary school and even in kindergarten (e.g., NRC 2012). Research has succeeded in demonstrating that science content knowledge can successfully be fostered in kindergarten (Leuchter et al. 2014; Reuter and Leuchter 2021; Steffensky et al. 2012). Often, these interventions build on an inquiry-based design with a blend of scientific-thinking processes and science content knowledge (e.g., Lazonder and Harmsen 2016). Therefore, the question of when basic scientific-thinking skills develop and how stable they are, is an important one. Our findings show that young children's scientific thinking and their inquiry skills are just emerging in kindergarten age, which suggests that educators and designers of learning environments need to consider children's skill level, offering them adequate degree of structure to support development (see e.g., Fridman et al. 2020; Klahr et al. 2011; Weber et al. 2020).

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