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Effects of an extracurricular science intervention on elementary school children's epistemic beliefs: A randomized controlled trial

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Background. Further developing students' thinking about knowledge and knowing in science (epistemic beliefs) is considered a normative goal of science education in many countries around the world, even for elementary-school-aged children.

Aims. The goal of the present study was to introduce and evaluate a new intervention in science education aimed at developing children's epistemic beliefs, epistemic curiosity, and investigative interests. The intervention included an inquiry-based learning approach as well as reflections on epistemic issues because these methods are currently seen as most promising for fostering students' epistemic beliefs.

Sample. Data were collected from 65 elementary school children in Grades 3 and 4 (58.46% boys, age: $M = 8.73$, $SD = 0.60$) who participated in a voluntary extracurricular STEM enrichment programme in south-west Germany.

Methods. We investigated the effectiveness of the intervention by applying a randomized block design with a treated control group and repeated measures. The effectiveness of the intervention was analysed via multiple linear regression analyses.

Results. The results indicated that the children assigned to the intervention developed more sophisticated epistemic beliefs and a higher level of epistemic curiosity than the children assigned to the control condition. No intervention effects were found on investigative interests.

Conclusions. The results provide initial evidence for the effectiveness of the intervention and demonstrate that it is possible to improve epistemic beliefs among elementary school children in Grades 3 and 4. The study provides a starting point for understanding how young children develop epistemic beliefs.

Promoting student achievement and competencies in the STEM disciplines (Science, Technology, Engineering, Mathematics) is a cornerstone of current educational research and practice (OECD, 2016). Besides obtaining knowledge in these disciplines, it is also relevant for students to understand *how* such knowledge is generated. The respective key questions are as follows: Is our knowledge certain, or does it change over time? Do all

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questions in science have one right answer? Should one believe what is written in science books? Is knowledge disseminated by authorities, or does it develop through social interactions with others? and Answers to these questions refer to conceptions about the nature of knowledge and knowing in science (epistemic beliefs [EB], Mason & Bromme, 2010). They are central goals of science education and are relevant for understanding the fundamental elements of our world and for being responsible citizens in a society determined by science and technology (OECD, 2016).

Several studies have confirmed that science EB are positively related to school achievement (e.g., Greene, Cartiff, & Duke, 2018; Madjar, Weinstock, & Kaplan, 2017; Trautwein & Lüdtke, 2007; Tsai, Jessie Ho, Liang, & Lin, 2011) and science understanding (Elby, Macrander, & Hammer, 2016). Studies have also demonstrated that more sophisticated science EB are positively related to students' motivation and higher levels of self-concept and self-efficacy (Buehl & Alexander, 2005; Chen, 2012; Mason, Boscolo, Tornatora, & Ronconi, 2013; Urhahne & Hopf, 2004) as well as interest in science (Fujiwara, Laulathaphol, & Phillips, 2012).

Owing to the great importance of EB, several attempts have been made to foster students' EB as early as the elementary school level, for instance, via interventions or targeted science instruction in school (see Bendixen, 2016; Muis, Trevors, & Chevrier, 2016). Such approaches have included inter-alia, inquiry-based science learning, hands-on activities, or critical reflection (e.g., Bendixen & Rule, 2004; Conley, Pintrich, Vekiri, & Harrison, 2004; Ryu & Sandoval, 2012). Although evaluations of the effectiveness of such approaches are essential, empirically valid evaluation studies with adequate designs are still lacking, particularly at the elementary school level (Bendixen, 2016; Valla & Williams, 2012). However, because these children are in the 'curiosity golden age' (e.g., European Commission, 2007, p. 12), this age group is ideal for addressing existing misconceptions (see Kuhn & Weinstock, 2002) and for promoting interest and motivation in science.

To expand research in this area, our goal was to develop and evaluate a new intervention for elementary school students in Grades 3 and 4 who are typically 8 to 9 years old. The intervention focused primary on fostering children's EB (Conley *et al.*, 2004). Because motivational dispositions are relevant in the context of science learning and have been positively affected by science interventions (e.g., Ainley & Ainley, 2011; Hulleman & Harackiewicz, 2009; Potvin & Hasni, 2014), we explored effects on motivation (i.e., epistemic curiosity and investigative interests) as secondary outcomes. We examined the effectiveness of the 10-week intervention by employing a randomized block design with a treated control group and repeated measures (Torgerson & Torgerson, 2001). The intervention was part of an extracurricular STEM enrichment programme. To participate, children have to be nominated by their teachers, usually on the basis of interest, motivation, and school performance.

Theoretical conceptualization of EB

Epistemic[1] beliefs are subjective beliefs about the *nature of knowledge* (beliefs about what knowledge is) and the *nature of knowing* (beliefs about the process through which one comes to know something; Hofer & Pintrich, 1997; Lederman, 2007). The domain

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[1] *The terms* epistemic *and* epistemological *beliefs are used interchangeably in the literature. For the sake of simplicity, we use only the term* epistemic *in this paper.*

generality or specificity of EB has been extensively debated, and research in the respective disciplines (e.g., science and history) has made a strong case for the domain specificity of EB (Sandoval, Greene, & Bråten, 2016). Thus, in our intervention, we focused on fostering EB in the domain of science.

Concerning science EB, one major line of research has focused on identifying dimensions of EB (mainly by using self-report measures), and a debate has ensued on this issue (see Chinn, Buckland, & Samarapungavan, 2011; Hofer, 2016). However, there is consensus that EB are multidimensional, and several more or less independent dimensions of EB can be discerned (Hofer, 2016). In our study, we refer to a four-factor structure of science EB (Conley *et al.*, 2004) because this structure is in line with previous research on science EB (Elder, 2002; Hofer & Pintrich, 1997; Schommer, 1990) and has already been applied successfully to samples of various age groups, including elementary school children (Chen, 2012; Conley *et al.*, 2004). The four factors split into beliefs about the nature of knowledge (*certainty* and *development of knowledge*) and beliefs about the nature of knowing (*source* and *justification of knowledge*).

The *certainty* dimension reflects beliefs about the (lack of) changeability of knowledge in the natural sciences. Sophisticated stances include statements about the possibility of further development in scientific knowledge and a variety of answers to complex problems. The *development* dimension is associated with the belief that science is an evolving discipline. Sophisticated stances include statements about how scientific ideas are continually changing (e.g., on the basis of new evidence). The *source* dimension addresses knowledge beliefs that reside in external authorities. Sophisticated stances include critical evaluation, an avoidance of 'blind faith' in authorities such as teachers, and the ability to generate knowledge through one's own thinking. Finally, the *justification* dimension refers to the role of experiments and how claims are evaluated. Sophisticated stances include justifications for assessments and the acceptance of a variety of explanations for scientific phenomena (Conley *et al.*, 2004).

Motivational dispositions

Motivational dispositions are important in the context of science learning and understanding and have been shown to be positively affected by science interventions and activities (e.g., Ainley & Ainley, 2011; Hulleman & Harackiewicz, 2009; Loukomies *et al.*, 2013). Therefore, we also focused on the effects of the intervention on motivation, namely epistemic curiosity and investigative interests.

Epistemic curiosity

Epistemic curiosity is important in the context of science learning, where problems very often require the elimination of knowledge gaps and the genesis of new knowledge (Kuhn, 2011). Epistemic curiosity reflects the desire for knowledge, which motivates individuals to learn new ideas, close information gaps, and solve intellectual problems (Litman, 2008; Litman & Spielberger, 2003). It has been found to be positively related to EB, exploratory behaviour, complex problem-solving, and learning outcomes (e.g., Hardy, Ness, & Mecca, 2017; Litman, Hutchins, & Russon, 2005; Richter & Schmid, 2010). Although epistemic curiosity is considered a rather stable personality trait (e.g., Hardy *et al.*, 2017), there is also evidence that it can be aroused by, for instance, participating in competitive hands-on activities in the domains of science and technology (Hong, Hwang, Szeto, Tai, & Tsai, 2016). Also, inquiry-based learning approaches have been described as potential ways to foster students' curiosity (Pluck & Johnson, 2011).

Investigative interests

In addition to epistemic curiosity, investigative interests (one of Holland's vocational interest dimensions) are related to students' science learning (Ainley & Ainley, 2011; Carnevale, Smith, & Melton, 2011). Holland (1997) classified vocational interests as *Realistic*, *Investigative*, *Artistic*, *Social*, *Enterprising*, and *Conventional* (*RIASEC* model) and assumed that these interests represent preferences for activities that encompass the entire range of different occupations. Investigative interests are related to occupations in science, and students with high levels of investigative interests tend to prefer activities that involve thought, observation, investigation, and discovery (Holland, 1997). Thus, investigative interests might lead students to engage in more practical activities that are part of scientific inquiry and might therefore be important for the development and fostering of their understanding of science. In general, empirical evidence has revealed that investigative interests are positively related to math and science abilities (Ackerman & Heggestad, 1997). Although investigative interests are considered traits (Nauta, 2012), there is evidence that interests can be fostered through, for instance, inquiry-based instruction and extracurricular science experiences (e.g., Jocz, Zhai, & Tan, 2014; Wang, Wu, Yu, & Lin, 2015).

Promoting children's EB: Existing approaches and their effectiveness

Owing to repeated calls for the early promotion of students' EB (e.g., OECD, 2016), a variety of approaches have been developed for in-school as well as extracurricular settings (e.g., Bendixen, 2016; Valla & Williams, 2012). In comparison with secondary-school-level interventions, not much research has focused on elementary-school-level interventions until more recently (see Bendixen, 2016; Trevors, Muis, Pekrun, Sinatra, & Muijselaar, 2017). However, the number of studies focusing on epistemic change in this age group has been increasing (e.g., Kittleson, 2011; Metz, 2011; Ryu & Sandoval, 2012). We will review the most important approaches that have been applied in elementary school students in Grades 1 to 5 (who are usually 6–11 years old).

Metz (2011), for instance, investigated 'practical epistemologies' in science classes over a 2-year period in a sample of 6- to 7-year-old first graders. The aims of this approach included teaching the goals of scientific inquiry, scaffolding students' ideas, and supporting them in designing their own experiments. After this multicomponent intervention, the EB of the students became more sophisticated (e.g., regarding the uncertainty of results and strategies for improving research designs). Ryu and Sandoval (2012) did not focus on specific science EB dimensions but on the improvement of 8- to 10-year-old third- and fourth-graders' epistemic understanding as a result of sustained argumentation in a classroom intervention. They found that the students successfully learned how to evaluate arguments and to apply evidentiary criteria in their written arguments (e.g., causal claims and citation of evidence). Conley *et al.* (2004) found that the epistemic beliefs of fifth-grade students could be enhanced during a 9-week 'hands-on' science intervention that emphasized science skills as the implementation of a scientific investigation. The results showed that students' beliefs about the source and certainty of knowledge became more sophisticated. Cotabish, Robinson, Dailey, and Hughes (2013) used inquiry-based science units that engaged students in Grades 2 and 3 in creative and critical thinking through investigations and problem-solving. The results revealed positive effects not only on students' content knowledge but also on their epistemic understanding of the process by which knowledge in science is generated.

In sum, these studies provide insights into methods that are promising for fostering epistemic aspects such as certainty beliefs in class. However, the research designs of most of these studies have been limited; for instance, the instructional designs were confounded with a specific teacher (e.g., Ryu & Sandoval, 2012), or there was no appropriate control group (e.g., Conley *et al.*, 2004), which restricted the significance of the results. To add to prior research and to investigate causal relations, we used a randomized controlled design, which corresponds to the requirement for more experimental intervention studies on epistemic cognition with appropriate control groups (see Bendixen, 2016). To foster EB in young children on a broad level, we aimed to develop a new comprehensive as well as efficient 10-week programme for students in Grades 3 and 4, who are typically 8 to 9 years old. To add to previous interventions, we intended to foster all relevant dimensions of science EB (source, certainty, development, and justification) simultaneously. To this end, we combined and adapted the most promising methods and design principles for fostering EB as hands-on activities, inquiry-based learning, and constructivist or explicitly reflexive approaches in which teachers initiate critical discussions of epistemic issues or scientific argumentation (e.g., Akerson & Hanuscin, 2007; Ryu & Sandoval, 2012). Furthermore, we included methods that have shown promise with students at the secondary school level, for instance, the evaluation of contradictory or conflicting evidence in scientific investigations (Bendixen, 2016; Kienhues, Bromme, & Stahl, 2008). Additionally, we aimed to promote motivational dispositions within the same science intervention for the first time. In order to reach this goal, we included intellectually challenging problem-solving tasks and science activities that were intended to stimulate epistemic curiosity as well as investigative interests (see Jocz *et al.*, 2014; Pluck & Johnson, 2011).

Description of the intervention

The science intervention – a 10-week course titled 'Young Researchers – We work like Scientists' – was aimed primarily at fostering children's EB and secondarily at fostering their epistemic curiosity and investigative interests (Oschatz & Schiefer, 2017). To achieve these goals, the course focused on the epistemic aspects of science (Duschl, 2008), namely to help children understand the process of knowledge building and refining and to get them to think about what they know, what knowledge is, how it can be used, and how they know what they know (Sandoval *et al.*, 2016). Children were given many opportunities to conduct their 'own' research in order to adopt the epistemic norms and practices that are common across the disciplines of the natural sciences (e.g., the coordination of theory and evidence, seeing knowledge as an object of inquiry, and using scientific arguments). To foster motivational dispositions, the intervention included cognitively challenging problem-solving and inquiry tasks requiring the elimination of information gaps and the genesis of new knowledge.

Teaching science content knowledge was not a main goal of the course, but different topics were used to illustrate the epistemic aspects of science (e.g., How does the weight of an object influence its speed?). The intervention followed a standardized script, and all children worked on all topics, which built upon one another. The science course addressed topics that are already covered in elementary science education (e.g., the

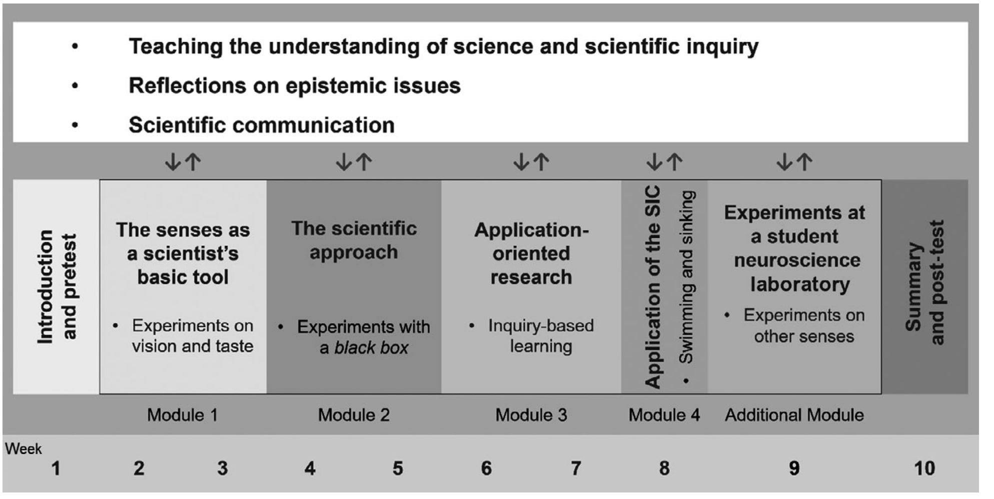

Figure 1. Course concept of the intervention.

functioning of the human senses) as well as unfamiliar topics (e.g., physical experiments about speed or research in a student neuroscience laboratory; see Figure 1). In investigating these topics, the children had the opportunity to think critically about science and learn about the epistemic aspects of science (see Kittleson, 2011). This means, for example, that through experience, the children came to understand that theories are developed on the basis of new evidence, that ideas or hypotheses are influenced by social exchange and communication between scientists, and that their own observations, perceptions, or interpretation of evidence might be limited or flawed. A typical course sequence included the following procedure: discussion of the research project children worked on at home ('research homework', group circle), short introduction to the topic and input of the course instructor (group circle), exercise or demonstration (in pairs or with the whole group), active inquiry phase (in groups of two to three children), presentation and discussion of results (group circle, guided by the course instructor), and reflection on results and inferences (group activity, guided by the course instructor).

The theoretical framework for the science intervention was an inquiry-based approach through which we sought to positively influence students' beliefs about the nature and generation of scientific knowledge as well as their motivation (e.g., Cotabish *et al.*, 2013; Minner, Levy, & Century, 2010). It included mainly elements of guided inquiry (see Klahr, Zimmerman, & Jirout, 2011) and a step-by-step unfolding of the inquiry process (Colburn, 2000). Within each topic, the children's 'research projects' began with fully guided experiments and direct instruction (see Klahr & Nigam, 2004), followed by types of structured inquiry, and finally more open types of guided inquiry (in which, e.g., only the research question and materials were given to the students). This framework was intended to provide insight into the process that formed the basis of the genesis and the change in scientific knowledge (Elby *et al.*, 2016).

The intervention furthermore included a transition from hands-on activities to more complex processes of reflection and thinking about knowledge and knowing (Aebli, 1980). Because such a reflexive approach is important for promoting an appropriate understanding of science (Akerson & Hanuscin, 2007; Metz, 2011), the children conducted practical research projects and discussed their findings afterwards in a guided group discussion (see Ryu & Sandoval, 2012). This approach was intended to increase the level of abstraction and reflection in each individual course session and across the course as a whole. The explicit integration of conflicting information (e.g., if different methods of investigation were applied and thus produced different results) further reinforced the promotion of epistemic doubt as a central mechanism for change in EB (Bendixen & Rule, 2004; Ferguson, Bråten, & Strømsø, 2012; Kienhues *et al.*, 2008). For instance, the children conducted 'research projects' in which separate groups compared and discussed their contradictory results on the same topic (e.g., Do heavy or light objects sink?).

The present study

Our goal was to present and evaluate a newly developed science intervention for elementary school students in Grades 3 and 4 who are typically 8 to 9 years old. The intervention focused primarily on promoting EB, which are essential for students' science learning and understanding of science (Lederman, 2007; Trautwein & Lüdtke, 2007), and secondarily on the related motivational dispositions of epistemic curiosity and investigative interests. We used a randomized block design with a treated control group and repeated measures to estimate the average causal effect of the programme (Torgerson & Torgerson, 2008).

The intervention involved learning settings that allowed students to actively participate in the scientific inquiry process and reflect critically on the epistemic issues that arose. Thus, we expected to find positive effects of the intervention on children's EB (Hypothesis 1). In addition, the intervention addressed several aspects of science learning and inquiry and required students to eliminate information gaps and deal with scientific issues. Therefore, we expected to find positive intervention effects on epistemic curiosity (Hypothesis 2a) and investigative interests (Hypothesis 2b) as well.

Method

Sample

Data were collected from 65 elementary school children (58.46% boys, age: M = 8.73, SD = 0.60, Grade 3: N = 33, Grade 4: N = 32) who participated in a voluntary extracurricular enrichment programme in south-west Germany (*Hector Children's Academy Program, HCAP*; see Golle, Herbein, Hasselhorn, & Trautwein, 2017). Children have to be nominated by their teachers to take part in the programme, with nominations based on motivation and interest as well as school performance. After children are admitted to the general programme, they are allowed to choose from a variety of afternoon enrichment courses at 60 local sites. Four HCAP sites participated in the present study and included the intervention in their regular course programme where the children and their parents could choose courses on a voluntary basis. The participating children were from 24 different schools and 26 classes. The intervention group consisted of 32 children (62.5% boys, 56.25% Grade 3, age: M = 8.74, SD = 0.58), whereas the control group consisted of 33 children (54.54% boys, 45.45% Grade 3, age: M = 8.75, SD = 0.58).

Experimental design

We investigated the effectiveness of the intervention using a randomized block design with a treated control group and repeated measures (pre-test [T1], post-test [T2]). In order to enable randomization, the intervention course and the control course (speech training) were offered as a two-part course sequence titled *Talking about science—With others and to others*. The courses took place over two semesters. After registering for the course sequence, the children in each of the four participating academies were randomly assigned to either the intervention or the control group. The children who participated in the intervention course during the first semester participated in the control course during the second semester, and vice versa. Furthermore, there was a second post-test [T3] for the children in the initial intervention condition after they participated in the speech training course in the second semester. Both courses were developed and implemented by university researchers and always took place at the same time (the groups met for 90 min once a week for 10 weeks). Combining the two courses allowed us to assume that the intervention group did not differ from the control group in terms of interest in science and scientific topics. This study design has the advantage that, in line with ethical principles for intervention studies, all participants received the treatment (Emanuel, Wendler, & Grady, 2000). It also minimized the risk of attrition between pre-test and post-test and allowed us to control the activities of the children in the control group.

Data collection took place during the first and last two parallel course sessions in the first semester. Five to 10 children were enrolled in each course. Trained research assistants administered the questionnaires. Prior to testing, we obtained parents' written consent for their children's participation. The study was approved by the ethics committee of the university's Faculty of Economics and Social Sciences (Approval Number *AZ.: B2.5.4._aa_2013/10/23*).

Description of the control condition: The speech training course

In the speech training course, the children's speeches addressed a self-selected topic and were presented to the group at the end of the course. The topics ranged from the description of pets to the solar system or chemical experiments. The primary focus of the course was on how to prepare and deliver a speech competently (Herbein *et al.*, 2018). The science topics were mainly used to illustrate, impart, and practice different public speaking skills (i.e., non-verbal, organizational, and language use skills). Thus, both interventions had the overarching aim of dealing with science and scientific topics. However, the control-group children did not learn anything about epistemic aspects of the nature of science, scientific inquiry, or the conditions under which scientific knowledge is generated. It could therefore be assumed that the two interventions were different enough to detect specific treatment effects.

Implementation fidelity

To establish the validity of the inferences drawn from the science intervention, implementation fidelity (the degree to which an intervention is implemented as intended) must be established (Carroll *et al.*, 2007; Wigelsworth, Lendrum, & Humphrey, 2013). In this case, a detailed course manual was prepared to ensure that the intervention was conducted as intended (O'Donnell, 2008). It included a theoretical introduction, a description of the aims of the intervention and each course unit, and a detailed description of each course unit and experiment. It also contained guiding questions for the scientific discussions and debates. Furthermore, detailed time limits were given for each element within each unit. The intervention was offered at the four academies by the course developers from the university (three of the authors). Overall, there were only slight differences in the implementation of the programme (e.g., 5- to 10-min deviations from the timetables). All deviations were documented.

The speech training course (control condition) was implemented in all four groups by the same researcher from the university who had developed the course (Herbein *et al.*, 2018). To ensure treatment fidelity, a detailed course manual was prepared and pre-tested in a pilot study. The course instructor followed the manual carefully. All teaching materials were equal in the four groups, and detailed time frames were given for all exercises.

Measures

Epistemic beliefs were assessed with a 26-item instrument (Conley *et al.*, 2004; German version by Urhahne & Hopf, 2004). Four subscales reflect the dimensions of source (e.g., 'Only scientists can observe natural phenomena', α ($t1/t2$) = .73/.74), certainty (e.g., 'Scientific knowledge is always true', α ($t1/t2$) = .73/.75), development (e.g., 'Sometimes scientists change their minds about what is true in science', α ($t1/t2$) = .58/.73), and justification of knowledge (e.g., 'It is good to try experiments more than once to make sure of your findings', α ($t1/t2$) = .58/.64). Items were rated on a 4-point Likert scale ranging from 1 (*I completely disagree*) to 4 (*I completely agree*). The source and certainty items were recoded for the analyses because more negation of the source and certainty items represented more sophisticated EB. After we recoded these items, higher scores reflected more sophisticated EB for every scale. All questions were read aloud to the children to ensure that the children's reading capacity did not influence their understanding of the items.

Epistemic curiosity was assessed with a 14-item instrument developed by Litman and Spielberger (2003). The items address the desire for knowledge, which motivates individuals to learn something new and solve intellectual problems (e.g., 'I always like learning something new', α ($t1/t2$) = .86/.86). Items were rated on a 4-point Likert scale ranging from 1 (*never*) to 4 (*always*).

Investigative interests were assessed with seven items that comprise the investigative interest subscale (e.g., 'How interested are you in looking at something under a microscope?'; α_{t1} = .78; α_{t2} = .57) from the 42-item children's version of the RIASEC vocational interest questionnaire by Holland (1997). The items were rated on a 5-point Likert scale ranging from 1 (*not at all*) to 5 (*very much*). Due to lack of time, the RIASEC was sent home, and the children filled out the complete questionnaire at home.

Children's fluid intelligence was measured with the Culture Fair Intelligence Test (CFT 20-R; Weiß, 2006). It consists of 56 items across the four subscales of continuing series, classifications, matrices, and topological conclusions (α = .77). Fluid intelligence was assessed as a control variable in order to characterize the study sample (participants in an enrichment programme) and rule out systematic differences between the intervention and control groups.

Statistical analyses

The effectiveness of the intervention was analysed via multiple linear regression analyses in Mplus (Muthén & Muthén, 1998–2012). All analyses used the robust maximum-likelihood estimator, which corrects standard errors for the non-normality of the variables. The dependent variables were the z-standardized post-test measures from the previously described scales. The predictors in our regression models were group assignment

(0 = control, 1 = intervention) and the z-standardized pretest score for each dependent variable (see Enders & Tofighi, 2007). Owing to the standardization of the dependent variables, the multiple regression coefficient of the group variable indicated the standardized intervention effect (effect size,[2] *ES*), controlling for the corresponding pretest score. One-tailed tests of significance (α = .05) were used in all analyses because we formulated directional hypotheses. To estimate differential intervention effects due to the respective pretest scores, interactions between group assignment and the pretest scores were added to the models. Prior to the intervention effects, we report descriptive statistics, differences between the intervention and control groups (*t*-tests and effect sizes), and correlations between the outcome variables at T1 and T2.

Missing data

There was no differential dropout between the two groups, $\chi^2(1,65) = 3.05$, $p = .081$. However, some children missed single course sessions owing to illness or other reasons. Therefore, missing values occurred across all variables that were assessed at school at rates of between 6.25 and 21.88% (see Table 1). Because the RIASEC questionnaire on vocational interests was filled out at home, the investigative interest scale had 33% missing values. Furthermore, when comparing the means of the dependent variables at pre-test for

Table 1. Descriptive statistics for the scales: means, standard deviations, and internal consistencies

			T1				T2			
	Construct		*N*	*M*	*SD*	α	*N*	*M*	*SD*	α
Epistemic beliefs (Conley *et al.*, 2004)	Source of knowledge[a]	IG	32	2.19	0.53	.73	30	2.62	0.58	.74
		CG	31	2.20	0.62		26	2.50	0.67	
	Certainty of knowledge[a]	IG	32	2.60*	0.66	.73	30	2.92	0.67	.75
		CG	31	2.23*	0.57		26	2.44	0.53	
	Development of knowledge	IG	32	3.27*	0.40	.58	30	3.50	0.40	.73
		CG	31	3.49*	0.38		26	3.31	0.55	
	Justification of knowledge	IG	32	3.51	0.33	.58	30	3.55	0.32	.64
		CG	31	3.57	0.36		26	3.41	0.39	
Motivational dispositions	Epistemic curiosity (Litman & Spielberger, 2003)	IG	32	3.10	0.48	.86	31	3.17	0.46	.86
		CG	32	3.19	0.42		25	3.07	0.38	
	Investigative interests (Holland, 1997)	IG	31	4.00	0.81	.78	28	4.15	0.48	.57
		CG	33	4.15	0.63		22	4.14	0.46	
Covariate	Fluid intelligence[b] (Weiß, 2006)	IG	30	119.07	15.06	.77	–	–	–	–
		CG	28	118.32	15.40		–	–	–	–

Note. N = *n*umber of participating children, *M* = mean, *SD* = standard deviation, α = Cronbach's alpha. Measurement time points: T1 = November 2013, T2 = February 2014. IG = intervention group, CG = control group. *t*-Tests for independent samples (IBM SPSS, version 22) were calculated to test for significant differences between the IG and the CG at T1.

[a]Items were recoded so that higher scores reflected more sophisticated beliefs.

[b]Fluid intelligence was measured once in the middle of the course.

*$p < .05$.

[2] *Effect sizes can be classified as follows: small:* d = *0.20, medium:* d = *0.50, and large:* d = *0.80 (Cohen, 1992).*

the children missing at post-test with children who were not missing at post-test, no significant differences were found (all $ps > .05$). This is compatible with the assumption that the missing data were missing at random (Enders, 2010). For this reason, we applied the full information maximum-likelihood approach implemented in Mplus to deal with the missing values (Muthén & Muthén, 1998–2012). This method takes all measured variables into account to estimate the model parameters (Schafer & Graham, 2002). Regarding the follow-up (T3) measure, there was a high rate of dropout between T2 and T3 in the initial intervention group (37.5%) because some of the children were interested in participating in only one of the two courses from the course sequence. Due to the large dropout and the fact that no control measure was available at T3, we did not include these measures in further analyses.

Results

Descriptive statistics

Table 1 presents all scales that were administered as well as their corresponding descriptive statistics and Cronbach's alpha values. In a first step, we analysed the characteristics of and differences between the intervention and control groups at T1 (see Table 1). Participants had a mean IQ of 118.71 ($SD = 15.10$), slightly more than one standard deviation above the average IQ in the norm population. There were no IQ differences between the intervention and control group, $t(57) = 0.19$, $p = .853$, $ES = -0.049$. We found differences between the two groups at T1 on certainty of knowledge, $t(61) = 2.45, p = .017, ES = -0.616$, in favour of the intervention group; and development of knowledge, $t(61) = -2.28, p = .026, ES = 0.574$, in favour of the control group. There were no significant group differences in the other scales; source of knowledge: $t(61) = -0.10$, $p = .992$, $ES = 0.002$; justification of knowledge: $t(61) = -0.63$, $p = .530$, $ES = 0.159$; epistemic curiosity: $t(62) = -0.80$, $p = .426$, $ES = 0.2$; and investigative interests: $t(62) = -0.81, p = .420, ES = 0.203$. We controlled for the pretest score on each scale in all regression analyses. Intercorrelations between all outcome variables at T1 and T2 are shown in Table 2.

Intervention effects

Hypothesis 1 concerned the intervention's promotion of children's epistemic beliefs. In line with our hypothesis, the findings showed that the children assigned to the intervention exhibited more sophisticated epistemic beliefs than the children assigned to the control condition at the end of the first semester. Overall, three out of four scales were positively affected by the intervention (see Table 3).

Children in the intervention group scored significantly higher than children in the control group on the post-test measures of certainty ($B = 0.45, p = .025$), development ($B = 0.61, p = .010$), and justification ($B = 0.43, p = .038$). Thus, participants exhibited more sophisticated views on the potential uncertainty of knowledge in science and on science as an evolving and changing subject. They also reported more sophisticated stances on the role of experiments and the acceptance of a variety of explanations for scientific phenomena (see Conley *et al.*, 2004). No intervention effect was found for source ($B = 0.18, p = .223$). There was no significant difference between the two groups in the development of the children's beliefs about knowledge residing in external authorities.

Table 2. Intercorrelations between the Scales

Construct	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) Source of knowledge T1	1												
(2) Certainty of knowledge T1	.63**	1											
(3) Development of knowledge T1	−.14	−.06	1										
(4) Justification of knowledge T1	−.22	−.16	.52**	1									
(5) Epistemic curiosity T1	−.05	−.14	.45**	.47**	1								
(6) Investigative interests T1	.30*	.20	.38**	.35**	.37**	1							
(7) Source of knowledge T2	.47**	.36**	−.11	−.14	−.11	.05	1						
(8) Certainty of knowledge T2	.29*	.59**	−.19	−.17	−.14	−.12	.61**	1					
(9) Development of knowledge T2	.25	.15	.25	.38**	.43**	.25	.06	.12	1				
(10) Justification of knowledge T2	−.04	.12	.22	.45**	.24	.19	−.10	.08	.55**	1			
(11) Epistemic curiosity T2	.08	.05	.32*	.29*	.69**	.35**	−.10	−.12	.19	.46**	1		
(12) Investigative interests T2	.14	.02	.36*	.21	.38**	.42**	.11	.08	.23	.05	.33*	1	
(13) Fluid intelligence	.06	.15	−.16	.07	−.08	.12	.18	.34*	.25	.26	−.01	−.06	1

Note. $^{*}p < .05$; $^{**}p < .01$.

Table 3. Course effects on epistemic beliefs: predicting children's post-test measures

	Source of knowledge (T2)[a]		Certainty of knowledge (T2)[a]		Development of knowledge (T2)[a]		Justification of knowledge (T2)[a]	
Variables	*B*	*SE*	*B*	*SE*	*B*	*SE*	*B*	*SE*
Treatment[b]	.18	(.23)	.45*	(.23)	.61*	(.26)	.43*	(.24)
Pretest score[a]	.49***	(.11)	.53***	(.11)	.38***	(.10)	.44***	(.13)
Explained variance (R^2)	.25		.40		.17		.23	

Note. One-tailed significance levels are reported for the pretest score and the treatment because we tested directional hypotheses.
[a]Variables were z-standardized prior to the analyses.
[b]The treatment was dummy-coded 0 = control group and 1 = intervention.
*$p < .05$; ***$p < .001$.

To investigate whether any intervention effects depended on children's initial epistemic belief scores, interactions between the group variable and each pretest score were additionally included in the regression analyses. The only significant interaction was between course participation and the certainty of knowledge pretest scores ($B = -0.25$, $p = .017$); that is, the children in the intervention group with lower pretest scores benefitted more from the intervention than the children in the intervention group with higher pretest scores. Including a dummy variable (1 = high pretest scores on certainty, 0 = low pretest scores on certainty), the results revealed that both groups benefitted from the intervention but that the effect was higher for the students with low pretest scores on the certainty scale. Overall, the findings revealed that children's epistemic beliefs were positively affected by the intervention.

Hypotheses 2a and 2b concerned the intervention's promotion of the motivational dispositions. In line with Hypothesis 2a, the results revealed that the children assigned to the intervention group scored significantly higher on epistemic curiosity ($B = 0.34$, $p = .041$; Table 4) than those assigned to the control group. They reported a greater desire for knowledge and greater motivation to learn something new and solve intellectual problems.

Table 4. Course effects on epistemic curiosity and investigative interests: predicting children's post-test measures

	Epistemic curiosity (T2)[a]		Investigative interests (T2)[a]	
Variables	*B*	*SE*	*B*	*SE*
Treatment[b]	.34*	(.19)	.12	(.26)
Pretest score[a]	.69***	(.09)	.42***	(.16)
Explained variance (R^2)	.49		.18	

Note. One-tailed significance levels are reported for the pretest score and the treatment because we tested directional hypotheses.
[a]Variables were z-standardized prior to the analyses.
[b]The treatment was dummy-coded 0 = control group and 1 = intervention.
*$p < .05$; ***$p < .001$.

Contrary to Hypothesis 2b, no intervention effect was found for investigative interests ($B = 0.12$, $p = .318$). There was no difference between the two groups in the development of the children's interests in solving problems, performing experiments, conducting research, or engaging in activities involving thought, observation, investigation, or discovery.

Discussion

This study tested whether the EB, epistemic curiosity, and investigative interests of elementary school children in Grades 3 and 4 could be fostered by a new extracurricular science intervention based on inquiry-based learning elements and reflection on epistemic issues. We applied a robust research design with a treated control group, randomization, and repeated measures to test the effectiveness of the intervention. In general, the results revealed small- to medium-sized positive effects for the enhancement of both sophisticated EB and epistemic curiosity. However, the intervention did not affect children's investigative interests. Overall, the results provided initial evidence for the effectiveness of the intervention and demonstrated that it is possible to improve EB and motivation among children in Grades 3 and 4. Thus, the combination of design principles applied in the intervention seems to be a promising approach for fostering third- and fourth-graders' EB. In the following sections, we discuss the results of the study with regard to their educational relevance.

Fostering epistemic beliefs

The science intervention positively affected participants' EB. Children became more sophisticated in their stances about the certainty, development, and justification of knowledge. Specifically, children with low prior beliefs on certainty of knowledge benefitted from the intervention and improved their beliefs compared with children in the intervention with high prior certainty beliefs. This indicates that the intervention was particularly beneficial for students with misconceptions in this area. Overall, students shifted towards an understanding that 'scientific knowledge is tentative and evolving rather than certain and fixed, complex and interconnected rather than piecemeal, justified by appeals to evidence and coherence rather than authority, and constructed by people rather than perceived in nature' (Elby *et al.*, 2016, p. 113). This perspective enables children to have a deeper understanding of the (ongoing) further development of knowledge, which is essential for their science learning and understanding of the 'nature and development of scientific knowledge' (Duschl, Schweingruber, & Shouse, 2007, p. 36). No intervention effects were found for the development of children's beliefs about sources of knowledge, which the questionnaire presented as having a critical view rather than 'blind faith' in external authorities such as teachers. Because the intervention focused on having the students conduct their own inquiries, the role of external authorities might not have been relevant for the course or might not have been a subject of discussion.

Fostering motivational dispositions

As expected, we found positive effects on the development of epistemic curiosity. The intervention elements might have activated children's enjoyment of thinking and given them insights into new issues. Because the children in the control condition intensively engaged with a self-selected scientific topic as part of their preparation for their final presentation, the results indicate that the intervention fostered epistemic curiosity to a greater extent than would occur by simply engaging with a specific science topic. Furthermore, the results provide initial evidence that students' motivational dispositions can be fostered by presenting them with cognitively challenging inquiry tasks (see Pluck & Johnson, 2011). This indicates that not only might epistemic curiosity be a prerequisite for science learning, but it can also be fostered through scientific inquiry or by reflecting on epistemic issues.

No intervention effect was found for children's investigative interests (Holland, 1997). One reason for this could be that the children might not have associated the items (which also included questions such as 'How much do you like reading newspaper articles about difficult topics') with investigative activities, and some of the items contained topics that were not addressed in the intervention. It is also important to take into account the possibility that our short-term intervention might not have had the power to change a trait-like construct such as vocational interests and that there was a dropout of 33% because the questionnaires were filled out at home. Because our sample consisted of participants in an enrichment programme (i.e., children who were nominated because of their high level of interest in science), there might also have been ceiling effects because of the selective sample (i.e., high pretest scores and lack of variance).

Limitations and future research

Although our study demonstrated the beneficial effects of a new intervention, some limitations should be considered. First, the generalizability of our study is limited. Our sample consisted of children who were nominated for an enrichment programme on the basis of interest, motivation, and cognitive abilities. They participated in the courses voluntarily and were therefore assumed to bring along a high level of intrinsic motivation. However, because the children's EB and cognitive abilities were not correlated with one another, we can assume that the intervention effects cannot be attributed solely to the specific sample used in the study. The intervention concept will need to be adjusted before being implemented in other settings such as regular school classes. Future research might focus on replicating this study with different samples or adapting the intervention for the school context. As there is evidence that the science course was particularly beneficial for children with prior misconceptions, it might be fruitful to implement it beyond the enrichment programme in more representative samples (e.g., school classes). The fact that the course was taught by university researchers also limits the generalizability of the programme and the extent to which it might transfer to other course instructors. However, the choice of researchers as instructors ensured a high level of implementation fidelity, which was particularly important for the initial evaluation of the programme (see Carroll *et al.*, 2007). The next step would be to evaluate the programme under real-world conditions, with teachers or regular course instructors conducting the implementation.

Second, it was difficult to find appropriate instruments for this age group. Few questionnaires are available for elementary school children, and there has been little research on the characteristics and measurement of EB among children in grades lower than Grade 5 using paper-and-pencil tests such as the questionnaire by Conley *et al.* (2004). The subscales we used had low-to-moderate reliabilities, which may have decreased the extent to which substantial intervention effects could be identified. Still, the reliabilities were comparable to the study by Conley *et al.* (2004). Future research could add more open-ended, qualitative measures (e.g., interviews or think-aloud protocols; see Mason, 2016) or class observations (e.g., analyses of student discussions) to detect qualitative changes in students' EB. However, to be suitable for intervention studies, such measures must be appropriate for group-testing situations and economical for large sample sizes.

Third, no conclusions can be drawn about the long-term effects of our intervention. Therefore, future studies should track students' development over a longer period of time and should take additional outcomes into account. Longitudinal study designs could be applied to investigate whether children continue to exhibit benefits from participating in the intervention even after the transition to secondary school. Longitudinal designs would also be appropriate for exploring whether children's EB affect their later science achievement or even their vocational choices.

Fourth, some limitations regarding the design of the study have to be taken into account. For example, the course instructors and the participants were not blind due to the randomization, and this may have influenced the results. However, in facing the challenges of conducting randomized controlled field trials, most of the quality criteria (see Schulz *et al*., 2017) were fulfilled.

Concluding remarks

First, our results provide initial evidence that the new intervention was able to foster 8- to 9-year-old elementary school children's EB and motivational dispositions. Therefore, the main objectives of the intervention were fulfilled. The design of the intervention and the combination of elements of past interventions were successful in positively affecting children's thinking about epistemic issues and their thirst for knowledge (Elder, 2002). The elements of the intervention and basic design principles appear to have been appropriately selected, adapted, and combined. However, we do not know which specific elements were particularly relevant in accounting for the intervention effects because it was a multicomponent intervention. The effect sizes were small to medium but comparable to previous interventions (e.g., $0.20 < ES < 0.36$; Conley *et al*., 2004). Because we used a robust research design, our results broaden existing approaches and provide initial evidence for the effectiveness of a new comprehensive as well as efficient programme and indicate that the intervention can foster young children's thinking about knowledge and knowing in science. Second, to the best of our knowledge, this is the first targeted intervention to show that it is possible to simultaneously foster several dimensions of epistemic beliefs as well as motivational dispositions in children in grades lower than Grade 5.

Second, to the best of our knowledge, this is the first study to show that it is possible to foster multiple dimensions of epistemic beliefs in children in grades lower than Grade 5. Our findings are in alignment with Smith, Maclin, Houghton, and Hennessey's (2000) conclusion that 'elementary school children are more ready to formulate sophisticated epistemological views than many have thought' (p. 350). Our findings strengthen the call for educators to incorporate aspects of science EB in addition to science content in order to foster comprehensive science learning among young students. This might establish an important basis for their later science learning and understanding (Duschl *et al*., 2007) and prepare them for later life in a society that is greatly impacted by science and technology (Bybee, 1997).

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