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Changes in epistemological beliefs in elementary science students☆

AnneMarie M. Conley,* Paul R. Pintrich, Ioanna Vekiri, and Delena Harrison

Combined Program in Education and Psychology, The University of Michigan, Ann Arbor, MI 48109, USA

Abstract

Epistemological beliefs, or beliefs about the nature of knowledge and knowing, are currently a target of increased research interest. The present study examined two research questions: (1) how do epistemological beliefs change over time? and (2) what role do gender, ethnicity, SES, and achievement play in their development? The study was correlational with an ethnically diverse sample of 187 fifth grade students (46% Latino, 27% Anglo, and 27% African American, and 67% low SES). Self-report questionnaires that tapped four dimensions of beliefs (source, certainty, development, and justification) were given to students at two time points during the course of a nine-week science unit. Results showed that students became more sophisticated in their beliefs about source and certainty of knowledge over time, but that there were no reliable changes in development and justification. There also were no main or moderating effects of gender or ethnicity, but there were main effects of SES and achievement. Low SES and low achieving children had less sophisticated beliefs in comparison to average SES and high achieving children. There were no significant interactions between gender, ethnicity, SES, and achievement for any of the four belief measures. Results are discussed in terms of personal and contextual factors and their role in the facilitation of epistemological belief development.

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* Corresponding author. Fax: +1-734-615-2164.
E-mail address: ampm@umich.edu (AM.M. Conley).

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1. Introduction

Epistemological beliefs, or beliefs about the nature of knowledge and knowing, are currently a target of increased research interest. Although there is a diversity of research on these beliefs, there are two general traditions that characterize much of the research. First, from its earliest beginnings, research on students' personal epistemology has examined the nature of development and change in how students think about knowledge and knowing, especially in college students. More recently, there has been a second program of research that has examined how these beliefs can facilitate or constrain student understanding, reasoning, thinking, learning, and achievement (see Hofer & Pintrich, 1997 for review). The current study follows in the first tradition, but adds to the literature by examining change over time in young elementary school children's epistemological beliefs in science. In addition, we examine whether gender, ethnicity, socio-economic status (SES), and achievement moderate changes in these beliefs.

1.1. The nature of development and change in epistemological beliefs

Since Perry's (1970) early work with college students in the 1960s and 70s, questions of change and development have been paramount in research on epistemological beliefs (Hofer & Pintrich, 1997; Pintrich, 2002). There are at least two important questions that must be addressed in developmental research in general: (1) what changes, and (2) how can we describe the nature of the changes. There has been progress on these two questions in the research on epistemological beliefs, but there is still a need for research on these issues, especially with younger children, as so much of the developmental research has focused on college students (Pintrich, 2002).

In terms of the first question, there has been debate about what changes exactly, and various models and theories have ranged from proposing one general dimension of epistemological thinking that changes over time in a stage-like manner (e.g., Perry, 1970), to models that propose some finite number of dimensions, usually four to seven (e.g., Hofer & Pintrich, 1997; Schommer, 1990), to models that propose many different dimensions or epistemological resources (e.g., Hammer & Elby, 2002). In his review of this research, Pintrich (2002) acknowledged the lack of consensus about the number of dimensions in the current research, but suggested that models that propose some finite number of dimensions may offer the best compromise. In particular, models that offer more than one dimension seem better able to take into account the domain specificity of epistemological thinking in comparison to stage-like models that are more domain general (Hofer & Pintrich, 1997; Pintrich, 2002). At the same time, a focus on some finite number also seems reasonable from a cognitive perspective that recognizes domain specificity, in contrast to a large or unlimited number of epistemological resources from a strong situated perspective (cf. Hammer & Elby, 2002; Pintrich, 2002). We followed the cognitive domain specific perspective in this study and examined four dimensions of epistemological beliefs in the domain of science.

Nevertheless, even if there are multiple dimensions of epistemological beliefs, there is still debate about the nature of the dimensions. In contrast to earlier work on epistemological thinking that took a stage-like developmental approach, work beginning with Schommer (1990) looked at development in terms of a set of distinct beliefs that developed more or less independently of one another. Schommer hypothesized five dimensions of epistemological beliefs including: *Stability* (tentative to unchanging), *structure* (isolated to integrated), *source* (authority to observation and reason), *speed* of acquisition (quick or gradual), and *control* of acquisition (fixed at birth or lifelong improvement). Evidence for all but the source belief was found using exploratory factor analysis on data from college samples. Schommer (1993) also replicated the four-factor structure with high school samples. Other groups of researchers have found five factors with revised versions of Schommer's instrument (e.g., Bendixen, Schraw, & Dunkle, 1998; Jehng, Johnson, & Anderson, 1993). More recently, Schraw, Bendixen, and Dunkle (2002) developed the Epistemic Beliefs Inventory (EBI) to measure dimensions similar to those proposed by Schommer (1990). In factor analyses of data from college students, the EBI yielded five reliable factors that matched Schommer's dimensions, which they labeled: *Certain knowledge* (stability), *simple knowledge* (structure), *omniscient authority* (source), *quick learning* (speed), and *innate ability* (control).

Although there is empirical evidence for these five factors, Hofer and Pintrich (1997) have argued that the last two dimensions, quick learning (speed) and innate ability (control), are not epistemological dimensions, as they do not really focus on the nature of knowledge and knowing, but rather on the nature of learning. To be sure, there should be correlations between individuals' beliefs about knowledge and knowing and their beliefs about learning; however, they are not the same construct conceptually and theoretically. Hofer and Pintrich (1997) have suggested that there are four general epistemological dimensions including *certainty of knowledge* (stability), *simplicity of knowledge* (structure), *source of knowing* (authority), and *justification for knowing* (evaluation of knowledge claims). The first three of these dimensions parallel those proposed by Schommer (1990) and Schraw et al. (2002), while the last dimension, justification, is more often proposed by those who take a more developmental perspective on epistemological development (Hofer, 2000; King & Kitchener, 1994). Kuhn (1991) and Elder (2002) have provided some initial empirical support for these dimensions in both college and younger student samples. In this study, following Hofer (2000) and Elder (2002), we focused on four dimensions of epistemological beliefs that have to do with the nature of knowledge and knowing in science.

As has been noted, much of the empirical research on epistemological beliefs has focused on older populations (college and high school students), in part because it was assumed that epistemological thinking was hard to identify among younger students (Kuhn, 1988). Work on children's theory of mind (Wellman, 1992) however, suggests that at least the precursors to epistemological thinking begin at an early age, perhaps as young as four years old, and that there should be some continuity in development between theory of mind and epistemological thinking (Chandler, Hallett, & Sokol, 2002). In addition, in the area of science education, thinking about knowledge claims, use of evidence, and the justification of knowledge is often the explicit goal or focus of instruction in the curriculum (e.g., National Academy of Science, 1996). Solomon and her colleagues (Solomon, Duveen, & Scott, 1994) interviewed 11- to 14-year-old students about the purpose of experiments, the relationship between scientists' ideas and their experiments, and the nature of scientific theories. They also asked students to provide an example of an experiment and explain how it helped them to understand a theory. Solomon et al. (1994) found it was rare, especially for the younger students, to think of scientific experimentation as a purposeful activity whose goal was to generate and test explanations. Neither did students seem able to differentiate between descriptions and explanations. In a subsequent large-scale study, in which Solomon and colleagues (Solomon, Scott, & Duveen, 1996) used the same questionnaire with a much larger age-range of students (13- to 18-years-old), the researchers found that older students' views showed a significant progression toward a sophisticated understanding of science. However, many of the older students still did not seem to understand the nature of theory and its relation to prediction and empirical evidence. There is a need for more research on younger students' epistemological beliefs in general, and in science in particular. The domain of science offers an important arena for the development of epistemological thinking given the focus on data and the use of evidence and may provide younger children with some of their earliest experiences with epistemological thinking.

In a recent study in this area, Elder (2002), using interviews and questionnaires, identified several dimensions that characterized fifth grade science students' epistemological beliefs. The questionnaire items were adapted for science from Rubba and Andersen (1978) and Schommer (1990), and were grouped into four scales similar to those already discussed: Changing nature of science (stability), coherence of knowledge (structure), source of knowledge (source), and role of experiments (refers to knowledge justification in science). Multidimensional scaling was used to investigate the underlying factor structure and three scales were created: change, source, and reason (combined role of experiments and source of knowledge items). The coherence (or structure) factor found by Schommer (1990) and Schraw et al. (2002) did not emerge with this younger population. Elder used these questionnaires, along with open-ended interview questions about the definitions of science and the sources of scientific ideas, to investigate and describe elementary students beliefs in science.

In general, Elder (2002) found that students' epistemological beliefs in science reflected both mature and naïve understandings with students endorsing relatively sophisticated statements about the changing nature of science. In particular, students strongly endorsed sophisticated statements about knowledge justification in science, supporting the idea that knowledge comes from reasoning, thinking, and experimentation. However, in their interviews, they also indicated a less sophisticated belief that the purpose of science was to do projects and activities, rather than explain phenomena. Students also saw their own role in scientific endeavors as passive, with most students reporting passive sources such as books, teachers, or family members as the source of scientific ideas. To scientists, they attributed a more active role, with scientists' ideas originating from curiosity, exploration, or interactions with the environment. The work described here builds on Elders (2002) work by considering how elementary students' beliefs change over time, and by investigating the role of gender, ethnicity, and SES.

Following this research, we investigated four dimensions of epistemological beliefs in fifth grade science classrooms: Source, certainty, development, and justification. These dimensions are similar to three of those found by Schommer (1990) and Schraw et al. (2002), and they are in line with the four dimensions in recent work by Elder (2002) and Hofer (2000). In addition, these four dimensions represent two general areas that Hofer and Pintrich (1997) argued are at the core of individuals' epistemological theories: Beliefs about the nature of knowing, and beliefs about the nature of knowledge. The source and justification dimensions reflect beliefs about the nature of knowing. Less sophisticated stances on the source dimension view knowledge as external to the self, originating and residing in outside authorities. This dimension is similar to the source dimension hypothesized, but not demonstrated empirically, by Schommer (1990), and the omniscient authority dimension hypothesized and found by Schraw et al. (2002). The justification dimension is concerned with the ways in which students use evidence and evaluate claims. In the domain of science, justification is primarily concerned with the role of experiments and the use of data to support arguments. This factor is similar to the reason factor in Elder (2002).

The other two dimensions reflect beliefs about the nature of knowledge. Less sophisticated stances on the certainty dimension reflect a belief in a right answer, in comparison to more sophisticated views that there may be more than one answer to complex problems. The development dimension is concerned with a belief that recognizes science as an evolving subject and that ideas and theories can change on the basis of new data and evidence. Students with more sophisticated stances endorse statements about ideas in science continuing to change, or discoveries in science leading experts to change what they think is true. Conceptualizing beliefs about the nature of knowledge in terms of certainty and development is slightly different from the work of Hofer (Hofer, 2000; Hofer & Pintrich, 1997), where beliefs in this general area have been considered in terms of certainty and simplicity. Both the development and certainty dimensions overlap with the certain knowledge dimension discussed by Schraw et al. (2002).

Given these four dimensions of source, certainty, development, and justification that define what develops, the second general developmental question concerns the nature of change in these beliefs over time. As Pintrich (2002) has pointed out, all the research in this area assumes that the nature of development is from less sophisticated epistemological thinking and beliefs to more sophisticated beliefs. Much of the explicit developmental research on epistemological thinking has examined stage-like changes over fairly long periods of time, such as longitudinal studies over the course of four years of college (e.g., Perry, 1970) or used cross-sectional designs and compared individuals of different ages in terms of their epistemological thinking (e.g., Kuhn, 1991). These studies do not provide much information about the nature of change over shorter time periods. In contrast, most research that has examined more specific dimensions has not examined change over time, except in relation to the test-retest reliability of the instrument (e.g., Schraw et al., 2002). However, there may be developmental changes that take place over shorter periods of time, especially in younger children as they begin to encounter issues about knowledge and knowing in school settings. Science classrooms may provide a particularly apt context to examine change over time in epistemological thinking given their focus on experiments, data, and evidence. Moreover, there is some evidence to suggest that particular types of science classrooms, that is, hands-on science classrooms that involve students in the design of experiments and the collection and analysis of data, may promote epistemological thinking (Solomon et al., 1996). Engaging in such activities might help students to understand that answers to questions do not come from authorities, but result from investigations and are subject to change. A small number of intervention studies (e.g., Carey, Evans, Honda, Jay, & Unger, 1989; Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; Smith, Maclin, Houghton, & Hennessey, 2000) have shown that even elementary school students can improve their understanding of the process of science with appropriate instruction.

Given this research, our first purpose in this study was to examine the change in young children's epistemological beliefs over the course of instruction in hands-on science classrooms. We expected that students would become more sophisticated in their epistemological thinking in terms of their beliefs about the source of knowledge, the certainty of knowledge, the development of knowledge, and the justification of knowledge. A change toward greater sophistication in beliefs would be evidenced by weaker beliefs in external authority as the source of knowledge and in the certainty of knowledge, and stronger beliefs in the developing nature of science and the role of evidence in justification.

1.2. Potential moderating effects of gender, ethnicity, SES, and achievement

Our second research question focused on the potential moderating role of gender, ethnicity, SES, and achievement. Although it is clear that epistemological beliefs change over the long term from less sophisticated to more sophisticated, there may be personal factors that can facilitate, or constrain development. In the research on epistemological beliefs, there is a fair amount of research on the role of gender differences, some on achievement level differences, but very little to none on the role ethnicity or SES may play in development. There is a clear need to examine these factors and to investigate how they might moderate or change the nature of development (Pintrich, 2002).

In terms of gender, there have been whole programs of research focused on demonstrating that there are important gender differences in epistemological thinking (e.g., Baxter Magolda, 1992; Belenky, Clinchy, Goldberger, & Tarule, 1986). However, there are many other studies that find almost no gender differences in epistemological thinking or beliefs (e.g., King & Kitchener, 1994; Kuhn, 1991). Pintrich

(2002) has recently suggested that there may not be important gender differences in epistemological thinking when it is defined in terms of separate dimensions of epistemological beliefs. That is, when individuals are asked to focus on specific dimensions of epistemological beliefs, rather than more holistic and general ways of thinking, gender differences do not emerge. In addition, when examining change over time, both males and females might show similar rates of development in reference to specific dimensions. In line with this reasoning, and following Pintrich (2002), we did not expect to find any gender differences in epistemological beliefs or in their change over time.

In terms of ethnic and SES group differences, there is a paucity of evidence on their role in epistemological thinking. However, given the current high interest in the role of ethnic and cultural differences in many domains of psychological and educational research including motivation, cognition, and achievement, it seems important to investigate the role of these factors in epistemological thinking as well (Pintrich, 2002). There may be two possible effects: There could be a main effect of group membership resulting in mean level differences in beliefs, or there could be a moderating effect, such that change over time is different for different groups. At the same time, it has been noted repeatedly that there is a need to separate out the effects of ethnicity from SES, and not make the mistake of comparing a sample of lower SES African American or Latino students with a sample of middle class Anglo students, thereby confounding ethnicity and SES (e.g., Graham, 1994; Pollard, 1993).

In addition, it is important to separate out the effects of achievement in these types of comparisons as there are ethnic and SES differences in achievement (Graham, 1994). The role of achievement in fostering the development of epistemological beliefs is not clear, but there are some studies that find that more sophisticated epistemological beliefs are associated with higher levels of achievement and learning (Hofer & Pintrich, 1997). We expected that achievement level would be associated with students' epistemological beliefs with higher achieving students expressing more sophisticated beliefs. In terms of ethnic and SES differences, we did not advance any directional hypotheses, given the lack of previous research on their role in epistemological development, but we did examine their relation to epistemological beliefs.

2. Method

2.1. Participants

Participants were 187 (57% female) fifth grade students in 12 elementary school classrooms in the southwest participating in hands-on science instruction. The sample was ethnically diverse (46% Latino, 27% Anglo, and 27% African American) and 67% of the students were eligible for free or reduced lunch. All five schools participated in the same district-wide hands-on science program, which consists of four units each school year through sixth grade, with many students starting as early as kindergarten.

2.2. Procedure

Data were collected in the spring of the school year as students worked on a unit on chemical properties. Epistemological beliefs were measured with self-report questionnaires administered in class at the start (Time 1) and after the completion (Time 2) of a nine-week hands-on science unit investigating chemical properties of substances, in March and May. Trained research assistants read items aloud to all students.

2.3. Science instruction

The study was conducted during a nine-week unit about chemical properties of substances, which was the third of the four science units studied in the fifth grade. This unit emphasized science process skills, including the ability to perform a science investigation, collect data, make observations, interpret results, draw conclusions, and justify conclusions on the basis of evidence from observations. During this unit, students tested common household substances (e.g., cornstarch) with reagents (e.g., iodine) to determine the identity of various "mystery powders." The other science units were: Circuits and Pathways, Crayfish, and Daytime Astronomy. The units included one- or two-period activities that gradually introduced students to more complex concepts and procedures and built on what the students had learned in previous lessons.

The content of the science instruction was constant across classrooms. The teachers who participated in this hands-on program received kits with all the materials they needed for their students, a teacher's guide, and performance assessments (materials, student handouts, and scoring forms) to administer in the middle and at the end of the unit. The guide for the unit provided a detailed description of every lesson (activities, instructional goals, materials, assessment strategies, and instructions on how to teach the lesson), background content information about chemical properties, and a list of other resources. The two main goals of the unit, as explained in the guide, were to: (a) help students learn about the chemical properties of substances by making direct observations, and (b) apply problem solving skills. The focus of student activities, as expressed in the content of the instructions, was on exploring phenomena, making and recording observations, and on generating and testing predictions. The guide suggested that after introducing every activity teachers should encourage students to explore phenomena and make their own discoveries using the materials provided. Next, the teacher was to lead a class discussion to guide students in the interpretation of the results of their explorations and to develop their understanding of science concepts. The guide provided suggestions for how to start the discussion, brief steps on how to carry it out and what questions to ask students, some examples of student–teacher dialogues, and also ideas for how to connect new ideas to old ones and to experiences outside the classroom. Although it emphasized that teachers should pay close attention to students' thinking, encourage the exchange of ideas in class, and question students about their observations and their predictions, the guide did not provide explicit suggestions on how teachers could help students draw conclusions and develop conceptual understandings based on their observations. In observations of a sample of these classrooms, it was clear that teachers emphasized explorations and observations, but not argumentation and reflection (Vekiri, Baxter, & Pintrich, 1998). This is characteristic of many hands-on science programs, and what often distinguishes them from inquiry-based programs (Herrenkohl et al., 1999).

Instruction in the observed classrooms usually involved three distinct phases. In the introductory phase, the teachers reviewed the activities and the main concepts that were taught in the previous lesson, introduced a new hands-on activity, explained the required procedures and materials it included, and gave instructions on what students had to record in their notebooks. In the second phase, students worked in small groups using materials while the teachers circulated among different groups providing feedback and guidance. The third phase was a whole-class session at the end of the lesson, in which students discussed the activity. There was some variability across the observed classrooms in the degree to which teachers focused on procedural aspects during the second phase of instruction, but all classrooms followed this general instructional sequence (Vekiri et al., 1998).

2.4. Measures

Epistemological beliefs were measured along four dimensions with a 26-item instrument adapted from previous work with elementary science students (Elder, 2002). Items were rated on a 5-point Likert scale ($1 =$ strongly disagree; $5 =$ strongly agree), and all questions were worded to have students focus on the domain of science (see Appendix A for a complete listing of all items and scales). Source (5 items, $\alpha s = .81$ (t1), .82 (t2)) was concerned with beliefs about knowledge residing in external authorities (e.g., "Whatever the teacher says in science class is true"). Certainty (6 items, $\alpha s = .78$, .79) referred to a belief in a right answer (e.g., "All questions in science have one right answer"). Development (6 items, $\alpha s = .57$, .66) measured beliefs about science as an evolving and changing subject (e.g., "Sometimes scientists change their minds about what is true in science"). Justification (9 items, $\alpha s = .65$, .76) was concerned with the role of experiments and how individuals justify knowledge (e.g., "Good answers are based on evidence from many different experiments"). The source and certainty scales were reversed so that for each of the scales, higher scores reflected more sophisticated beliefs.

Information about gender, ethnicity, SES, and achievement was collected from school records. Whether or not the student was eligible for free or reduced lunch served as an indicator of SES. Students eligible for free or reduced lunch were assigned a code of zero, while students who were not eligible for assistance received a code of one. Achievement was measured using a combination of math and reading achievement test scores from the Stanford Achievement Test; mean percentile ranks of the standardized reading and math scores were averaged to create a single achievement score.

3. Results

Our research concerns epistemological beliefs—how they change over time, and the role that gender, ethnicity, SES, and achievement play in their development. Since these beliefs form the basis of our analyses, it was important to provide empirical evidence for the assumed four-dimensional factor structure: Using confirmatory factor analyses (CFA) we replicated that the epistemological belief dimensions source, certainty, development, and justification are measured with the epistemological beliefs questionnaire. Based on the a priori mapping of items to factors, we tested the assumption that each item indicates exclusively its respective factor. This assumption would be rejected if this model would cause a significant misfit, indicated by relevant goodness of fit statistics (cf. McDonald & Ho, 2002).

For Time 1 epistemological beliefs, the minimum fit function χ^2 was statistically significant at 396.39 with 293 degrees of freedom. However, the root mean square error of approximation (RMSEA) of 0.038 indicated a very good fit. Additional fit indices, like the comparative fit index (CFI = 0.90), the non-normed fit index (NNFI = 0.89), and the root mean square residual (RMR = 0.062) supported the conclusion that the confirmatory model provided a reasonable fit for the data. These statistics were similar for Time 2 beliefs. A further inspection of the LISREL modification indices, which help to identify possible ways to improve the fit, suggested allowing for four residual correlations. No considerable model improvement could be expected from changes in the item-factor association (loading matrix), which corroborated the robustness of the underlying factor structure. The confirmatory factor analysis revealed considerable redundancy in the measures on the construct level, as indicated by the correlation matrix of the four latent variables: In particular the high correlation between the source and certainty scales ($r = .91$ at Time 1 and $r = .92$ at Time 2) makes it difficult to differentiate between both concepts logically.

Our first research question concerned the changes in students' epistemological beliefs in science. Table 1 presents zero-order correlations for the epistemological belief scales at Time 1 (March) and Time 2 (May). Correlations between Time 1 and Time

Table 1
Zero-order correlations of achievement and epistemological belief scales at Time 1 and Time 2 ($N = 187$)

	1	2	3	4	5	6	7	8	9
1. Source (T1)	—	.76**	.29**	.12	.70**	.69**	.36**	.17*	.39**
2. Certainty (T1)		—	.26**	.17*	.56**	.76**	.28**	.17*	.49**
3. Development (T1)			—	.47**	.36**	.29**	.50**	.30**	.29**
4. Justification (T1)				—	.19*	.12	.40**	.44**	.28**
5. Source (T2)					—	.72**	.38**	.16*	.46**
6. Certainty (T2)						—	.37**	.20*	.51**
7. Development (T2)							—	.57**	.27**
8. Justification (T2)								—	.22**
9. Achievement									—

Note. All scales are scored so that higher scores represent more sophisticated beliefs.
* $p < .05$.
** $p < .01$.

2 measures of the same belief ranged from $r = .44$ to .76, suggesting both change and stability over time within individuals. Also, shown in Table 1 is the correlation of the beliefs with achievement level, demonstrating that students who had higher levels of achievement also had more sophisticated beliefs.

Table 2 gives means, standard deviations, and the results of four separate paired t tests for the four epistemological belief scales at Time 1 and Time 2. From Time 1 to Time 2 there were changes in students' epistemological beliefs, with students evidencing more sophisticated beliefs at Time 2. From Time 1 to Time 2, students scored significantly higher on certainty and source, indicating a move away from beliefs that knowledge was certain and existed in external authorities, a change toward more sophisticated beliefs. Students' scores also were higher on development and justification at Time 2 than at Time 1, indicating more sophisticated beliefs about the evolving nature of science, and the role of experiments in knowledge justification. However, when group differences and achievement were accounted for, as in the next set of analyses, the changes over time for development and justification were no longer significant.

3.1. The moderating role of gender, ethnicity, and SES

Our second research question asked whether there were differences in mean levels of epistemological beliefs or in the degree to which epistemological beliefs changed over time across groups. For these analyses, we conducted four repeated-measures analyses of covariance (ANCOVAs, one for each belief measure) with gender, ethnicity (Latino, Anglo, African American), and SES (low, average) as the between-subjects factors, time as the within-subjects factor (Time 1, Time 2), and achievement as the covariate. Given that ethnicity and SES are often correlated with achievement levels, it is important to control for achievement differences in order to obtain reliable estimates of any ethnicity or SES effects. ANCOVA statistically adjusts for differences by including it as a continuous predictor in the analysis (Maxwell & Delaney, 1990). This allowed us to test whether different groups of students would differ in their epistemological beliefs if they were equivalent on achievement. Further, two of the cell sizes were small, yielding a nonorthogonal design (the two smallest cell sizes were 1 for male, Latino, average SES and 5 for female, African American, low SES, but most cells had over 15 students in them). Type III sums of squares were used in the absence of strong support for a non-zero interaction, as suggested by Maxwell and Delaney (1990).

Table 2
Changes in epistemological beliefs from Time 1 to Time 2 ($N = 187$)

	Time 1		Time 2		t value	p value
	M	*SD*	*M*	*SD*		
Source	3.68	.89	3.98	.80	7.09	.000
Certainty	3.38	.83	3.68	.83	7.16	.000
Development	3.90	.53	4.03	.54	3.39	.001
Justification	4.26	.39	4.34	.43	2.63	.009

Results from the ANCOVA are shown in Table 3. The main effect of time, which was significant in the *t* tests discussed above, was now significant for only two of the four epistemological beliefs. When achievement was accounted for, students' beliefs regarding development and justification did not change significantly from Time 1 to Time 2. Source and certainty beliefs showed a statistically significant increase, reflecting the expected developmental pattern of becoming more sophisticated over time. In addition, paralleling the zero-order correlations in Table 1, achievement was a significant covariate for all four beliefs, with higher achieving students showing a more sophisticated pattern of thinking across all four dimensions. It is important to note that the requirement for homogeneity of regression coefficients, an important assumption of ANCOVA, was tested and met, suggesting that the relations between the covariate (achievement) and the dependent measures (epistemological beliefs) were similar for the different groups of students (gender, ethnicity, and SES groups).

Main effects were found only for SES, not for gender, or ethnicity. As shown in Table 4, low SES students had lower scores on source, certainty, development, and justification than average SES students, indicating that low SES students tended to hold less sophisticated beliefs about knowledge and knowing. The means in Table 4 are adjusted for the achievement covariate and all group means are included, but only the differences between low and average SES students are reliably different within each time, not across time (the SES by time interaction was not significant). It is important to note that when the analyses were run without including SES as a between subject factor, the results suggested that there were ethnic differences in epistemological beliefs (with minority students showing less sophisticated beliefs). In other words, had we not included SES, we would have erroneously concluded that there were ethnic differences in epistemological beliefs, when in fact the only reliable

Table 3
Analysis of covariance results for each of 4 epistemological beliefs ($N = 187$)

Source	*df*	*F*			
		Source	Certainty	Development	Justification
Between subjects					
SES	1	6.93**	13.04***	7.02**	4.18*
Gender	1	.30	.22	.09	.26
Ethnicity	2	.62	1.15	.95	.36
Achievement	1	22.14***	36.7***	4.73*	4.87*
Between-group error	174	(.90)	(.75)	(.35)	(.23)
Within subjects					
Time	1	5.58*	13.13***	1.25	2.09
Within-group error	174	(.17)	(.16)	(.14)	(.08)

Note. Values enclosed in parentheses represent mean square errors. All of the 2-, 3-, and 4-way interactions among Time, SES, Gender, and Ethnicity were tested. None were significant and they are omitted from the table.

* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 4
Estimated marginal means for epistemological beliefs at Time 1 and Time 2 by gender, ethnicity, and socio-economic status, covarying out achievement ($N = 187$)

	Source		Certainty		Development		Justification	
	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Gender								
Male	3.86	4.15	3.45	3.89	3.95	4.12	4.29	4.29
	(.15)	(.14)	(.14)	(.13)	(.10)	(.10)	(.08)	(.08)
Female	3.75	4.09	3.42	3.79	3.96	4.05	4.26	4.40
	(.09)	(.09)	(.09)	(.08)	(.06)	(.06)	(.05)	(.05)
SES								
Low	3.60	3.88	3.19	3.53	3.79	3.97	4.18	4.27
	(.09)	(.08)	(.08)	(.08)	(.06)	(.06)	(.05)	(.05)
Avgerage	4.01	4.36	3.68	4.15	4.12	4.20	4.38	4.42
	(.16)	(.15)	(.15)	(.14)	(.11)	(.11)	(.08)	(.09)
Ethnicity								
Latino	3.61	4.15	3.34	3.87	3.87	3.94	4.30	4.25
	(.21)	(.19)	(.19)	(.18)	(.13)	(.13)	(.10)	(.11)
Anglo	4.02	4.13	3.64	3.88	3.98	4.16	4.29	4.43
	(.12)	(.11)	(.11)	(.11)	(.08)	(.08)	(.06)	(.07)
African American	3.79	4.08	3.33	3.77	4.01	4.15	4.25	4.37
	(.12)	(.11)	(.11)	(.11)	(.08)	(.08)	(.06)	(.07)

Note. Values enclosed in parentheses represent standard errors. For each scale, and within each time period, only the differences between low and average SES students are significant. Differences between Time 1 and Time 2 beliefs are depicted in Table 2.

differences were a function of SES, not ethnicity. Finally, there were no significant two-, three-, or four-way interactions between gender, ethnicity, SES, and time. In particular, the lack of any interactions between time and the other group variables means that gender, ethnicity, and SES did not moderate the change in epistemological thinking over the course of the study.

4. Discussion

In terms of our first question, there was evidence that young children's epistemological beliefs about science changed over time. Although the changes were not large, students became more sophisticated in their beliefs about the source of knowledge and the certainty of knowledge over the course of instruction. Even at Time 1, students endorsed a belief in observation and reason, rather than teachers and other experts, as the source of knowledge (Time 1 mean was 3.68, above the mid-point on the scale), but nevertheless, over time they came to agree with this belief even more. The pattern for certainty in knowledge was similar. Students began the study with fairly sophisticated beliefs about the certainty of knowledge (Time 1 mean was 3.38, closer to the mid-point, but still above it), but over time more strongly endorsed the idea that knowledge is not certain and that there may not be just one right answer in science. In contrast, the simple Time 1 to Time 2 increases in more sophisticated beliefs about development and justification were not reliable, once other factors were considered. However, entering a covariate in an ANCOVA reduces variance both within and between groups. Failure to find a significant effect of time on development and justification might be due to a decrease in power resulting from the reduction in the between group variance. On the other hand, it may be that in this sample, young children did not become more sophisticated in their beliefs about the development of justification of knowledge in science. Finally, the αs for these two scales were lower, suggesting less reliability over time. These findings are in line with Elder (2002), who found that students endorsed sophisticated statements about knowledge and knowing, as evidenced by the distance of the observed means from the midpoint of the scale. Comparing the Time 1 means for the students in this study with those reported by Elder suggests consistency across the two studies.

Of course, given the correlational nature of this study, no strong inferences can be made about the factors that contribute to the change in students' epistemological beliefs over time. Some caution also is warranted due to the low reliability of some of the scales. These analyses can, however, represent a first step in investigating these questions, and it does appear from the lack of any time by group interactions that the personal characteristics of gender, ethnicity, SES, and achievement are not related to changes in beliefs about source of knowledge and certainty of knowledge. There may be other personal factors involved such as prior knowledge in science, which should be investigated in future research. However, the lack of relations between the four personal characteristics and change in beliefs over time suggests that contextual factors might play a role.

We had no measures of contextual factors, but our classrooms were hands-on classrooms where the focus was on collecting data, making observations, comparing findings from different studies, and making claims using evidence. This type of science instruction is very different from textbook-driven instruction where students read a text and discuss the ideas or fill out worksheets and take tests on the material presented in the book or by the teacher. It is possible that this type of instruction would lead to less reliance on authorities such as the teacher or textbooks as well as some doubts about the certainty of knowledge, given the high potential for different students to generate different results from their hands-on experiments. Performing their own experiments and observations, as well as sharing differing results might have helped students understand that answers to questions do not come from authorities and are subject to revision and change. Our results parallel the findings of Solomon et al. (1996) that showed that hands-on science instruction was related to epistemological awareness. In this case, our students did become more sophisticated in their thinking about the source and certainty of knowledge. Of course, this potential explanation for the change needs to be tested in experimental studies that compare hands-on science classrooms with other more traditional elementary science instruction. Work in this area suggests that elementary school children in constructivist classrooms develop more sophisticated epistemological stances than do those in traditional classrooms (Smith et al., 2000).

On the other hand, students did not show significant improvement on the justification or development dimensions. The unit and teachers' materials were designed to encourage exploration and observation, but argumentation and reflection were not as emphasized. Observations in the classrooms suggested that students had limited opportunities to argue about their ideas using evidence and to reflect on their investigations. Much of the classroom talk revolved around procedural aspects of students' investigation (Vekiri et al., 1998). This might explain the absence of significant change along the justification and development dimensions. This potential change mechanism needs to be tested in experimental studies that compare hands-on science classrooms with more inquiry-based programs, which tend to place more emphasis on argumentation and reflection (Herrenkohl et al., 1999). The examination of how different contextual and classroom factors can lead to epistemological development will be an important avenue for future research.

Our second question concerned the potential moderating role of gender, ethnicity, and SES in epistemological development. First, in line with the proposition by Pintrich (2002) of no important gender differences, we found no evidence for main effects of gender or for any moderating effects of gender on development over time (no gender by time interactions). Boys and girls in the fifth grade were not different in terms of their thinking about the source of knowledge, the certainty of knowledge, or development and justification of knowledge. In particular, it is important to note that, contrary to much of the research on gender differences in epistemological beliefs (e.g., Baxter Magolda, 1992; Belenky et al., 1986), girls were not more likely than boys to endorse beliefs about knowledge residing in external authorities (teachers, scientists). At least in the science domain and for this sample, boys and girls seem to be very similar in their orientation to and beliefs about the nature of knowledge and knowing. It may be more profitable in future research to examine not gender per se, but gender orientation or identity as a moderator of epistemological beliefs given the lack of findings for gender (Pintrich, 2002).

In terms of ethnicity and SES, our results provide very strong evidence in support of Graham (1994) and others (e.g., Pollard, 1993) who call for separating out the effects of ethnicity and SES in our research. Our results showed no reliable differences in epistemological thinking by ethnicity as well as no moderating effect of ethnicity in change over time in epistemological beliefs. In this sample, Anglo, African American, and Latino students all thought in similar ways about the source, certainty, development, and justification of knowledge in the science domain. Of course, there may be ethnic differences that emerge with older samples of students as they become more identified with their culture, or in other domains, such as in the social sciences, history, or English literature, where there is much less consensus on epistemological thinking and criteria, even for experts in those domains. These will be important directions for future research and, paralleling the suggestion for gender, it may be more important to examine how ethnic identity or acculturation moderates epistemological beliefs, rather than simple ethnic designations (Pintrich, 2002).

However, our results suggest that there are strong SES differences in how students think about knowledge and knowing. Lower SES students did have less sophisticated beliefs: That scientific knowledge is certain and resides in authorities, and is less likely to change. Lower SES students were also less likely to endorse statements about the importance of evidence in the justification of knowledge claims. In addition, these findings were independent of achievement level, so it was not just that low SES students were also low achievers with less sophisticated beliefs. However, there were no differences in change over time by SES (no SES by time interactions), so SES did not moderate the general change in epistemological beliefs. Though it is impossible from this study to make any inferences about the origination of these differences between low and average SES students, Pintrich (2002) proposed possible mechanisms for class effects. He acknowledged the possibility that there might be class differences in the underlying orientations, knowledge structures, implicit theories, or ways of thinking that might emerge from the nature of interactions with people and institutions in different contexts. Different groups may have different ways of representing knowledge and ways of thinking that could create group differences in epistemological thinking. It seems clear that this will be an important avenue for future research. One implication of this finding is that while science teachers may not have to attend to gender or ethnicity differences in their teaching about epistemology, our results suggest that they may want to consider how students from different socio-economic levels may react to science instruction and discussions about epistemological thinking and beliefs.

Finally, there were achievement level differences, with higher achieving students expressing more sophisticated epistemological beliefs. This result is not terribly surprising given previous research on the linkages between beliefs and achievement (Hofer & Pintrich, 1997). However, achievement level did not interact with time, so achievement level did not moderate the general change over time in epistemological beliefs. This result is encouraging for teachers who wish to promote epistemological development as it suggests that positive change can occur regardless of achievement level. In fact, from the lack of reliable interactions between time and any of the four personal characteristics, it appears that positive change can occur for all types of students, regardless of achievement, gender, ethnicity, or SES. This implies that teachers can concentrate on working with all students about their epistemological beliefs and thinking and can expect that all students, even if starting at different points (e.g., low SES students), can make similar progress in their development.

The high correlations observed between the source and certainty scales indicate that the hierarchical structure hypothesized by Hofer and Pintrich (1997) does not emerge with this sample. Source beliefs concern the nature of knowing, while certainty beliefs represent the nature of knowledge. Though correlations between these are to be expected, correlations above .90 at both time points do not support the hypothesis that these represent different dimensions. The 2×2 structure of beliefs about the nature of knowledge and the nature of knowing provide a powerful framework for thinking about epistemological beliefs, but that framework does not represent the pattern of results observed in this sample. High correlations among epistemological belief scales are not unique to this sample, however; others have reported similar findings. For example, Hofer (2000) found with a college sample that certainty and simplicity beliefs factored together. The redundancy in the measures suggests that future work could use fewer items to measures these constructs, resulting in a shorter instrument, but it is arguably more important for future investigations to focus on the reasons behind these high correlations.

Some of the limitations of this study have already been noted, such as the correlational design precluding any strong inferences about the nature of classroom instruction in fostering epistemological development. There may be something powerful in hands-on and inquiry-oriented instruction that promotes epistemological development, but this hypothesis awaits further study. The study also had a relatively small sample size and some of the cells in the three-way interactions (gender by ethnicity by SES) had few students in them, as discussed in the results section. Appropriate adjustments were made for the nonorthogonal design, but the power to detect reliable interactions was limited in some cells. We attempted to parse out effects due to ethnicity from those due to SES, by considering both variables in our analyses and by using a diverse sample, but race and ethnicity were still confounded to a degree. Larger and more diverse samples are needed to replicate our findings. Finally, the use of self-report instruments that focus students on specific aspects of epistemological beliefs may draw out more sophisticated beliefs than general interviews or discourse analysis of classroom language use (Hammer & Elby, 2002), although previous research has shown that there is at least a fair amount of agreement between interviews and questionnaires (Elder, 2002). There is a clear need for multi-trait, multi-method studies in this area to clarify the potential method variance artifacts from actual developmental differences in epistemological beliefs (Pintrich, 2002).

In summary, this study shows that young children have epistemological beliefs about science, at least in terms of their beliefs about the source, certainty, development, and justification for knowledge. These beliefs do show some change over time, even a relatively short period of time such as a nine-week science unit. More importantly, the results suggest that gender and ethnicity do not play as large a role in epistemological thinking and beliefs as achievement and SES. It seems likely that teachers and classrooms can influence the development of these beliefs and our results imply that one source of change might be the nature of hands-on and inquiry-oriented science instruction.

Appendix A. Self-report items used to measure epistemological beliefs

Source

Everybody has to believe what scientists say.
In science, you have to believe what the science books say about stuff.
Whatever the teacher says in science class is true.
If you read something in a science book, you can be sure it's true.
Only scientists know for sure what is true in science.

Certainty

All questions in science have one right answer.
The most important part of doing science is coming up with the right answer.
Scientists pretty much know everything about science; there is not much more to know.

Scientific knowledge is always true.
Once scientists have a result from an experiment, that is the only answer.
Scientists always agree about what is true in science.

Development

Some ideas in science today are different than what scientists used to think.
The ideas in science books sometimes change.
There are some questions that even scientists cannot answer.
Ideas in science sometimes change.
New discoveries can change what scientists think is true.
Sometimes scientists change their minds about what is true in science.

Justification

Ideas about science experiments come from being curious and thinking about how things work.
In science, there can be more than one way for scientists to test their ideas.
One important part of science is doing experiments to come up with new ideas about how things work.
It is good to try experiments more than once to make sure of your findings.
Good ideas in science can come from anybody, not just from scientists.
A good way to know if something is true is to do an experiment.
Good answers are based on evidence from many different experiments.
Ideas in science can come from your own questions and experiments.
It is good to have an idea before you start an experiment.

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