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Constraints on Conceptual Change: How Elementary Teachers' Attitudes and Understanding of Conceptual Change Relate to Changes in Students' Conceptions

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Abstract Like their students, teachers may hold a variety of naïve conceptions that have been hypothesized to limit their ability to support students' learning. This study examines whether changes in elementary students' conceptions are related to their teachers' content knowledge, attitudes, and understanding of conceptual change. The study takes place in the context of the adoption of a new unit on seasonal change in which students build and use sundials to observe seasonal differences in the apparent motion of the Sun across the sky. A mixed-method approach is used. Data sources include pre- and post-tests for students and teacher interviews and questionnaires. Results indicate that changes in students' conceptions may be related to their teachers' knowledge of the content, attitudes toward science, and understanding of conceptual change. One teacher had low attitude toward science and limited knowledge of conceptual change. After instruction, her students' responses became less accurate but more homogeneous than before instruction. The other teacher had high attitude and moderate knowledge of conceptual change. Her students showed gains from pre- to post-test, including responses that were more scientifically accurate than the teachers' initial answers.

Keywords Seasonal change · Elementary science curriculum · Primary science · Sundials · Attitudes · Conceptual change

Students hold a variety of alternative or naïve conceptions, which can negatively influence their performance on assessments and their ability to reason about natural phenomena. However, prior research has also shown that teachers themselves can

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hold alternative conceptions about natural phenomena (Burgoon et al. 2011). For example, in a recent study of teachers' and students' science misconceptions, Burgoon et al. (2011) found that teachers hold many of the same alternative conceptions as their students. They conclude that, "Teachers cannot be expected to effectively assist students in the reconstruction of their science conceptions if the teachers themselves have an inaccurate or incomplete understanding of the science concept" (p. 110). This statement has clear face validity—it is logically attractive to presume that it is impossible for teachers to impart correct information to students when they hold misconceptions. However, there is little direct evidence to support this relationship without confounding teachers' content knowledge, pedagogical knowledge, and teaching experience (Akerson et al. 2000). It has not been clearly established whether teachers' prior conceptions are the necessary endpoint of instruction, or if students can increase their content knowledge even beyond that of their teacher. In this article, I examine the possible relationships between teachers' content knowledge about seasons, their attitudes toward science, understanding of conceptual change, and possible changes in their students' conceptions.

Literature Review

I will review literature that fits roughly into three categories: conceptions of causes of the seasons by students and teachers; elementary teachers' attitudes toward science and science teaching; and connections between teachers' knowledge and their instruction for conceptual change.

Conceptions of the Causes of the Seasons

Seasons and their causes are an important topic that is typically first taught in elementary school (American Association for the Advancement of Science [AAAS] 2007). Beyond the curricular importance of the topic as a key piece of most state's science standards, learning about the seasons at primary grades connects with students' interests and future learning. First, most students around the world experience seasons and are interested in learning about them as a way of understanding patterns in nature and in society. The knowledge of seasons can also serve as a basis for children's future learning about the concepts of time, weather, and climate. Furthermore, if taught in a way that focuses on the relationship of Earth with the Sun, knowledge about seasons can also serve also an important basis upon which students can draw when learning about the solar system more generally.

Many students and teachers hold inaccurate understandings of the causes of the seasons, which often reflect naïve understandings about the nature of the Earth and its relation to the Sun. Prior research has examined such alternative conceptions in early childhood (Vosniadou and Brewer 1992) through primary (Lindgren 2003), secondary (Trumper 2001a, b), and post-secondary education (Schneps and Sadler 1988; Trumper 2001c), as well as among pre-service and in-service teachers (Atwood and Atwood 1996; Kikas 2004; Trumper 2003). Because the seasons and Earth's motion about the Sun are typically first taught in the primary grades

(AAAS 2007), appropriate instruction at this level may help students develop the desired conception of seasons (Lindgren 2003; Sharp et al. 1999).

A variety of alternative conceptions about the causes of the seasons have been examined, finding two very common alternative conceptions about the Earth-Sun relationship among both children and adults. The more common alternative conception is that the entire Earth is nearer the Sun in the summer than in the winter (Atwood and Atwood 1996; Roald and Mikalsen 2001; Schoon and Boone 1998). Under this conception, respondents typically do not know or do not consider that northern and southern seasons are reversed. The second common conception is that some part of Earth is closer to the sun during summer (Atwood and Atwood 1996; Sadler 1998). This conception may reflect efforts by individuals to accommodate the knowledge that northern and southern seasons are reversed. Other alternative conceptions are also present, such as the geocentric model (Atwood and Atwood 1996; Roald and Mikalsen 2001), and a great variety of idiosyncratic models (e.g., Maria 1997; Vosniadou and Brewer 1992).

Elementary Teachers' Attitudes Toward Science and Science Teaching

Elementary teachers' attitudes and beliefs can play an important part in their perceptions and practices of teaching science (Milner et al. 2012; Minogue 2010). In a recent article, van Aalderen-Smeets et al. (2012) review research on attitudes toward science of elementary teachers. They differentiate the different possible "objects" of a teacher's attitudes either as being toward science itself or toward the *teaching of* science. They propose a tripartite model: cognition (evaluative thoughts and beliefs), including relevance or importance, perceived difficulty of science, and gender differences; affect (emotions and moods), including enjoyment and anxiety; and behavior, including both enacted behaviors and behavioral intentions.

Elementary teachers' attitudes can have measurable relationships with their instruction in science and influence on students. For example, regarding the cognitive aspects of attitude (van Aalderen-Smeets et al. 2012), teachers' self-efficacy beliefs about teaching science are related to their students' performance on statewide achievement tests (Lumpe et al. 2012). Regarding the affective aspects of attitude, Choi and Ramsey (2009) find that elementary teachers with negative attitudes toward teaching science implemented inquiry-oriented science teaching unevenly. Regarding the behavioral aspects of attitude, teachers' attitudes toward teaching science and their perceptions that colleagues are teaching science are related to their intentions to teach science in their own classes (Milner et al. 2012). Furthermore, teachers with lower attitudes and lower content knowledge have been found to influence students negatively, resulting in lower student attitudes toward science and less growth in content knowledge (Jarvis and Pell 2004). While the study by Jarvis and Pell (2004) examines possible relationships between teachers' attitudes, knowledge, and student outcomes, that study does not look at the specific aspects of changes in students' conceptions—these are examined in the present study.

Teachers' Knowledge and Conceptual Change Instruction

As students' prior conceptions influence how they interpret and understand new information that they encounter (Posner et al. 1982), achieving conceptual change involves helping the learner experience dissatisfaction with the prior conception and find a new conception to be intelligible, plausible, and fruitful. Conceptual change may also require attention to the social context and to students' motivations and attitudes (Pintrich et al. 1993), particularly in elementary classes. Teaching science for conceptual change begins with eliciting students' prior conceptions to inform instructional choices (Barnett and Morran 2002). Instruction typically involves providing students with experiences that allow them to compare their expectations with observations of natural phenomena or other results, to examine discrepancies, and to identify whether and how a scientific explanation may be most fruitful (Asoko 2002).

Teachers who model and explicitly request expectations for drawing upon their own and others' ideas may provide valuable support for conceptual development (Beeth and Hewson 1999). Furthermore, while many elementary teachers are generally aware that students can hold alternative conceptions, relatively few are aware of their significance or how instruction should be adjusted to accommodate these conceptions (Duit and Treagust 2003; Gomez-Zwiep 2008). Therefore, pre-service and in-service teachers need more opportunities to develop skills with instructional strategies for conceptual change. This can be done in part by developing curriculum materials that support this pedagogical principle and that include repeated opportunities to practice it (Davis and Krajcik 2005).

In their study of possible connections between teachers' knowledge and instruction for conceptual change, Akerson et al. (2000) find possible relationships between teachers' experience, content knowledge, and instruction—when comparing experienced teachers with novice teachers. They concluded that teacher education programs should focus on giving teachers greater depth of content knowledge with a strong training in how to assess students' ideas and move forward for conceptual change. However, because the participating teachers' content knowledge and pedagogical knowledge are confounded with their tenure, it is not clear whether content knowledge or experience were more relevant issues. A consistent connection has not been demonstrated to show that a teacher's lack of conceptual mastery guarantees that students will fail to learn the scientific explanation or even adopt the teacher's naïve conception. But the general question remains, what aspects of a teacher's content knowledge and instruction *are* related to their potential success in supporting students' learning?

To examine this question it is important to understand possible relationships between changes in students' conceptions and their teachers' conceptions and instruction. In the present study, I explore these potential relationships in the context of an elementary science module on seasonal change. Specifically, I posed the following research questions: (1) How, if at all, do students' conceptions change after the implementation of a module on seasonal change? (2) What relationships exist between observed changes in students' conceptions and their teachers' conceptions and understanding of conceptual change instruction?

Methodology

Overall Study Design

The study consisted of a mixed-method design, with data collected over the course of one school year (Johnson and Onwuegbuzie 2004). I gathered data on teachers' conceptions of the seasons prior to the school year through a conceptual test. After returning the test, the teachers received the curriculum materials. With the teachers' assistance, I gathered student data using a conceptual test in early September and mid-May. I also engaged the participating teachers in interviews during the school year. In the following sections I provide more detail on the context and participants, curriculum materials, data sources, and analyses.

Context and Participants

The context for the study is an elementary school in a small school district in the western United States. The district is suburban; it has a median household income higher than the nearby city or outlying rural areas, but similar to other suburban towns in the vicinity. The district has a similar racial/ethnic make-up as other parts of its state.

The participants are two teachers and their students. The two teachers are Sharron and Martha (randomly-generated pseudonyms). Sharron teaches fourth grade and has over 10 years of elementary teaching experience. Martha teaches third grade and has over 15 years of elementary teaching experience. Of the two teachers, both participated in interviews about their attitudes and their instruction, but only Martha used the interview time to ask questions about the curriculum materials. The classes each consisted of 24 or fewer students. A third teacher expressed interest but opted out of the study before the school year began.

Curriculum Materials

The participating teachers implemented a curriculum module of lessons on seasonal change, with the major activities built around the sundial. The sundial has been used since antiquity to help people tell time, construct calendars, and understand seasonal patterns. Following this curriculum, the students use self-made sundials to record the apparent path of the Sun across the sky over the course of a day. This can be done by marking the shadow of the sundial's gnomon[1] at intervals of 30, 45, or 60 min, to create a *shadow plot*. Figure 1 shows a digitized shadow plot for reference. Teachers were recommended to have their students complete shadow plots one day in the fall, winter, and spring. For this study, I provided example shadow plots for the teachers in case of inclement weather (particularly in winter), to provide complete plots when students could not collect data all day (including shadows in the evening after school), and as an example of the summer shadow plot (in case the teacher could not schedule a data collection during this season).

[1] *Gnomon* is the part of the sundial that casts a shadow, from the Greek for "indicator.".

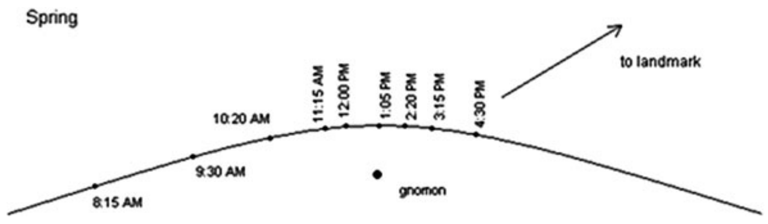


Fig. 1 A sample shadow plot (a recording of the shadow of a sundial's gnomon over the course of a day). The example is a digitized version of a plot collected in spring. A *solid dot* marks the gnomon's location. An *arrow* points to a distant landmark to ensure the sundial's position remains steady. Students note the tip of the gnomon's shadow the time of observation. A *curve* can later be drawn connecting the observed points

In addition to creating the shadow plots, other materials and activities are provided that help students learn more about the relationship of the Sun and Earth using the shadow plots. For example, in one lesson, students compare the angles of light that produce different types of shadows on a sundial. This helps them understand how the sundial can be used to deduce the angle of the sun above the horizon. In another lesson, students observe shadow patterns that a flashlight casts on a globe with a small gnomon. Again, this helps students connect the patterns seen in the shadow plots with the orientation of sunlight reaching the Earth and, thus, the relationship of the Earth with the Sun. Students also have opportunities to role-play the Sun and Earth in a classroom-sized model.

The lessons are adapted from *Tutorials in Introductory Physics* (McDermott et al. 2002) to be suitable for elementary students. All activities involve materials already available in elementary classrooms or easily acquired: toothpicks, paper, modeling clay, globes, and flashlights. I was available to provide teachers with additional materials as needed, but none were requested. The module includes explanatory documents and examples for the teachers, which encourage the teachers to elicit students' ideas and predictions about where and when the Sun rises and sets, the length of the day, and how students expect to observe the Sun in the sky in various seasons. The module also contained example questions that the teachers could use to elicit students' conceptions.

For the present study, the teachers received all the curriculum materials prior to the beginning of the school year. The interpretation, scheduling, and implementation of all activities were carried out by the classroom teachers based on their professional opinions and school and class schedules. I was available to answer questions if needed, both by telephone and email; but, there were few requests for further detail after the beginning of the school year.

Data Sources

I collected data from the teachers and their students. Student data come from responses to a conceptual test about the seasons, given in September and again in May. This test contains five open-ended items, including both drawing and explanation tasks. For example, the first question asks respondents to sketch a top-view of the orbit of Earth as it revolves around the Sun. The five items are provided in Appendix 1. The opportunity to draw and to explain are included to allow respondents to convey their ideas about the nature of the Earth-Sun relationship without explicit guidance from the item itself, as prior research has shown much variation in individuals' responses (Lindgren 2003; Vosniadou and Brewer 1992). The teachers administered the test to students at the beginning and end of the school year. The teachers then returned the completed tests. Students' identities could not be revealed with information provided on the questionnaire, as names were removed. The teachers created a coding system, marking each students' test with a number so that the pre- and post-tests could be matched. In total, complete data for both pre-test and post-test are available for 13 students in Sharron's class and 18 students in Martha's class.

Data on the teachers are of two types. First, the teachers completed a conceptual test similar to the students but with a few additional questions. Teachers received the test by mail in late summer before the beginning of the school year. They could complete and return it at their convenience, but had to finish it before receiving the curriculum materials. The teachers confirmed that they completed the test in one sitting, taking about 30 min for both the test and other questionnaires.[2] Second, teachers were asked to participate in semi-structured telephone interviews about their implementation of the module and their perceptions of conceptual change teaching. Each interview took approximately 1 h, and was scheduled to meet the teachers' schedule to ensure they had sufficient time and opportunity to respond fully. The interviews took place in the spring, after the teachers had completed the last lessons on the module but prior to the post-test. The interview focused on five particular aspects: the teachers' attitudes toward science and science teaching; teachers' identification of desired learning outcomes for a science unit; teachers' ideas about how prior knowledge may influence students' thinking; teachers' knowledge and use of formative assessment; and how the teachers plan lessons based on students' ideas. The interview tapes were then transcribed and prepared for analysis.

Data Analysis

Data analysis began with coding of students' tests and the teachers' tests and interview transcripts, followed by quantitative analysis and qualitative comparison. I coded students' test responses to allow for qualitative comparison with the teachers' responses and for transformation for quantitative analysis (Caracelli and Greene 1993). Coding first focused on attributes (Creswell 2012) such as the data source, time, and question. I then followed hypothesis coding (Saldaña 2009) to identify the relationship of students' responses to prior literature and to identify common language or drawings among responses. Hypothesis coding was selected because it can be particularly effective when prior literature is available to inform the initial generation of codes and themes (Saldaña 2009). The test response coding scheme focused on identifying responses consistent with (1) the scientific explanation, (2) alternative conceptions identified in previous research (e.g., Lindgren 2003), or (3) idiosyncratic

[2] As will be seen in the responses, there was no indication that teachers had "gamed" the test by drawing upon other sources when responding.

responses. For example, one test item asks students to draw the orbit of the Earth around the Sun. If a student drew a shape that was circular, this would be coded as consistent with the scientific explanation. On the other hand, if a student drew an oblate or oval orbit, with Earth nearer Sun in one or two locations, this would be marked as consistent with the distance-dependent conception. Teachers' test responses were coded using the same scheme.

For scoring the students' tests, some items were scored using partial credit, with the scientific response receiving full credit, alternative conceptions receiving partial credit, and blank responses receiving zero credit. The maximum possible score on the test was 9 points. A mixed two-way analysis of variance (ANOVA) was conducted, with students' total score as dependent variable, Class (two levels: Sharron and Martha) as the independent variable, and Time (two levels: pre-test and post-test) as a repeated measure. Prior to the mixed two-way ANOVA, the data were analyzed for violations of the test assumptions: normality, homogeneity of variance, and sphericity (Shavelson 1996). Regarding normality, results from Kolmogorov–Smirnov tests for normality were not significant ($p > .10$) for the pre- and post-tests. Regarding homogeneity of variance, Levene's test of equality of error variances showed no significant difference between the groups ($p > .10$). Regarding sphericity, because the data consists of exactly two time points, the sphericity assumption is always met (Girden 1992; Moulton 2009). With these assumptions met, the mixed two-way ANOVA was deemed appropriate for the current analysis, despite the small sample size.

In addition to quantitative analyses, students' responses were examined qualitatively for similarities or differences with their teacher's responses on the test. To do so, I drew upon the codes produced, examining the specific content of students' responses, and compared it with the text and drawings produced by the respective teacher. For example, I compared the particular language used in a student's explanation for the causes of the seasons with her or his teacher's answer on the same item, as well as with the answers of other students in both classes. In analyses of text responses, I focused on specific word choices, and whether there were common phrases across the students' and teachers' answers.

Exploring the teachers' understanding of conceptual change instruction is based on the telephone interview transcripts. As with the students' responses, I drew upon attribute coding and hypothesis coding (Saldaña 2009). I read each transcript and first coded each section for its relevance to one of the interview topics (attitudes toward science; science learning outcomes; ideas about students' prior knowledge; knowledge and use of formative assessment; planning lessons based on students' ideas). For the topic of attitudes, the responses were coded according to whether they conveyed positive or negative attitude toward science, and comfort or discomfort with teaching science (cf. van Aalderen-Smeets et al. 2012). For the other topics, responses were coded according to whether the teachers' responses indicated awareness of the importance of students' prior knowledge (cf. Duit and Treagust 2003) and use of strategies for conceptual change instruction (cf. Asoko 2002).

All coding was conducted by the author. To ensure the broad validity of the interpretations of the study, all transcripts, test results, and codes were reviewed by two colleagues: one with expertise in science education, and one with expertise in qualitative research methods. Feedback from both colleagues indicated that the patterns identified and interpretations raised were appropriate for the data.

Findings

Findings from the quantitative analyses of student test data are presented first, followed by findings from qualitative analyses of student tests, teacher knowledge and attitudes.

Quantitative Findings

Students' understanding of the causes of the seasons was measured at the beginning and end of the year using an open-ended instrument. Table 1 presents descriptive statistics on students' scores for both classes at the pre- and post-test. Next, a mixed two-way ANOVA was conducted on the students' total score, with Class, Time, and Class × Time interaction (Table 2). Results indicated no significant main effects for either Class or Time, but that there was a significant interaction ($F [1,58] = 11.21$, $p < 0.01$). A plot of the scores by class and time reveals the source of this interaction effect (Fig. 2). On the pre-test, Sharron's class had higher scores than did Martha's class, whereas at the end of the year Martha's class had higher scores than did Sharron's. The figure also demonstrates the finding from the ANOVA that the main effects for Class and Time are non-significant, as there is a strong crossover interaction. This strong crossover effect is supported by examination of the effect sizes (partial eta-squared, Table 2). About 16 % of the variance in the outcome scores can be attributed to the Class × Time interaction effect, after excluding variance explained by other predictors, whereas the main effects of Class and Time account for less than 5 % of the variance in the test scores. This indicates a moderately large effect of the interaction. The following section on qualitative findings adds further detail by examining the students' responses in parallel with the findings for the teachers.

Qualitative Findings

There are marked differences in the student results and in the test and interview responses for the two teachers. The sections below present findings from the teacher interviews and test responses, and examines possible relationships with students'

Table 1 Descriptive statistics for students' pre- and post-test scores, by class

Class	n	Pre-test		Post-test	
		M	SD	M	SD
Sharron	13	2.615	1.660	0.692	0.947
Martha	18	1.167	0.857	1.778	2.016

The maximum possible score was 9 points

Table 2 ANOVA results for pre- and post-test of understanding of the seasons

Source	*df*	F	Partial η2	*p* value
Intercept	1	68.21***	0.540	0.000
Class	1	0.23	0.004	0.633
Time	1	3.00	0.049	0.088
Class × Time	1	11.21**	0.162	0.001
Residual	58	(2.16)		

Value in parentheses is the residual mean-square

** $p < .01$

*** $p < .001$

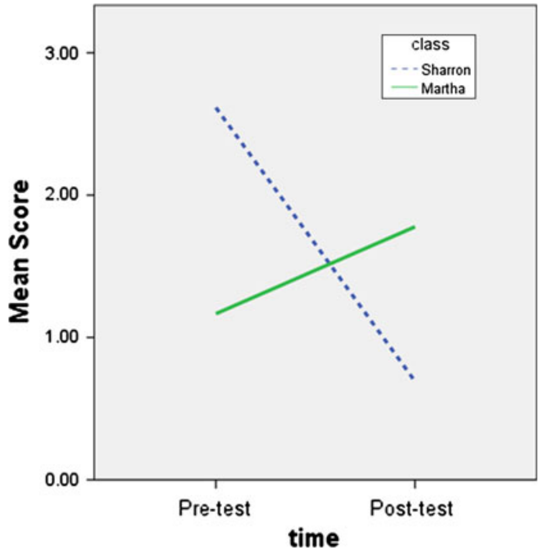


Fig. 2 Marginal means of test scores by time and class. The *dashed line* is for Sharron's class; the *solid line* is for Martha's class

answers are addressed. The results are presented first for Sharron and then for Martha.

Sharron's Interview

Sharron has been a teacher for 10 years. She teaches science in her classes, in particular by integrating it with other subjects such as reading or mathematics. Sharron admits she is not very comfortable teaching science, and it is among her least favorite subjects. Despite this, she tries to exhibit enthusiasm about science for her students to enjoy it and want to learn it, because she believes that "If you're interested in it, they're interested in it."

Sharron's goals for student learning in science are to address misconceptions directly: "If they have any misconceptions, then you correct them." In her view, it is very important to correct these misconceptions because "lots of kids have them."

She thinks these misconceptions are gathered through unreliable sources such as cartoons, TV, or misinformation from others.

To address students' misconceptions, Sharron seeks to show the students "what it [the scientific explanation] really is" and help them understand "why they are wrong." She believes that students "want to be right… [so] you give them something else that they can be right on." This suggests that Sharron teaches to identify and replace students' misconceptions to help students acquire the material that she must cover.

Sharron is aware of methods to acknowledge and incorporate students' prior conceptions in her teaching. She often uses a KWL chart (Ogle 1986) for her lessons, to identify what students already know, want to know, and then to follow up about what they learned. In addition, she likes to use a variety of strategies to understand students' prior knowledge, such as class discussion and questioning strategies, as well as giving the end-of-unit test at the beginning of the unit. She uses the information for various purposes. For example, she likes to "briefly reinforce what they already know" when it is correct. Additionally, if students already appear to know something she wishes to teach, it saves her time. However, she did not indicate using such assessment to address the students' naïve ideas about the concept.

Overall, Sharron's interview reveals that she has low attitude toward science and is uncomfortable with teaching it. She is aware that students have prior ideas and knowledge about a topic. Sharron appears to follow a "find and replace" approach to students' misconceptions (Smith et al. 1994), rather than creating opportunities for students to develop more scientifically appropriate conceptions.

Test Responses for Sharron and her Class

Sharron's test responses reveal a pattern of alternative conceptions of the seasons. In drawing a top view of the path Earth takes as it moves around the Sun, she draws an ovoid (egg-shaped) orbit, with Earth closer to the Sun in the summer. She further states that the Sun always rises in the east and sets in the west, and is never in the south or north. On an item to describe the cause of the seasons, Sharron writes that it is "the axis of the earth" but does not elaborate or explain her answer. Taken together, this suggests that Sharron has declarative knowledge about the cause of the seasons, but may exhibit naïve conceptions about the seasons when the declarative answer is not directly solicited.

Sharron's students show relatively good understandings of some aspects of the seasons on the pre-test. Table 3 presents results on the item in which students sketch a top-view of Earth's orbit as an example. Prior to instruction, the majority of responses (9 of 13) show a roughly circular orbit for Earth as it revolves around the Sun. Additionally, two of the students answer (correctly) that Earth is closer to the Sun in northern winter. However, at the post-test the majority of responses (8 of 13) show ovoid or oval orbits and only two students draw a circular orbit. Additionally, all of the students' respond on the post-test that Earth is closer to the Sun in the summer.

Table 3 Frequencies of sketch patterns for earth-sun revolution on pre- and post-assessments

Pattern	Sharron's class (n = 13)		Martha's class (n = 18)	
	Pre	Post	Pre	Post
Circular w/rotation[a]	0	0	0	1
Circular w/moon[a]	0	1	0	0
Circular[a]	9	2	8	11
Ovoid/oval[b]	3	8	7	3
Geocentric[b]	1	0	0	0
Other[b]	0	2	3	3

"Other" included blank depictions or those with patterns such as spiral orbits

[a] These patterns are considered appropriate or adequate

[b] These patterns are considered inadequate

An interesting pattern is also present in the students' responses about the cause of the seasons. At the beginning of the year, only 3 of 13 students indicate that the seasons are caused by the distance between Earth and the Sun. One student writes that it is because of "the tilt of the Earth," while another wrote that it was because of Earth's orbit. Others responses give descriptive statements about seasons (e.g., that summer is warmer) without indicating any cause for the phenomenon. However, at the post-test 10 of the 13 students referred to the spinning or rotation of the Earth.

Sharron's students have lower scores on the post-test, and have drawings and explanations that are more homogeneous on the post-test than on the pre-test. Most of these incorrect answers appear similar to Sharron's initial responses on the test.

Martha's Interview

Martha has been a teacher for over 15 years. She does not have formal training or background in the science discipline. Even so, Martha loves to teach science; it is one of her favorite subjects. She indicates that she has developed her interest and positive attitude through experiences teaching science to her students (cf. Ginns and Watters 1996).

Martha's goals for teaching science are to help students increase their understanding. She believes that students come to her class with some background knowledge about the world: "They know a whole lot…. They seem to have more knowledge of [science] than they do of math or reading." However, she thinks that "knowing is not the same thing as being able to understand and apply it." She wants to help them experience science and be able to adopt scientific ideas as their own. As she says:

> Even if you learn something, if it goes against what you think is common sense—but you don't really, truly experience and experiment with it enough to get it into your common sense—then you'll go right back to what you used to believe.

In her teaching, Martha tries to create opportunities for students to experience a phenomenon, make sense of the experience, and attempt to apply the new ideas. She often asks students to make a prediction, and then has them experiment with materials or observe a demonstration. She especially likes experiments “that kind of defy what they think should be happening.” Martha recognizes that some students will not fully adopt the scientific conception at the end of the experience, but hopes that through the interaction and with future instruction that students will move closer to understanding. She here recognized that students often begin with misconceptions, and that the refutation of that misconception does not necessarily lead to a new conception.

Martha uses a variety of assessment strategies at the outset of a science unit, similar to Sharron. She sometimes she used the final test as a pre-test, and if students do well enough the class may skip a topic or have more time for other topics. She has also adopted some pre-lesson activities from the school district’s science coordinator that seek to “guide students’ thinking,” which Martha prefers over declarative pre-tests because they are thought-provoking in their own right. With information from these assessments, Martha then determines if she should incorporate more reading activities, more experiments or activities, etc.

Test Responses for Martha and her Class

Martha’s assessment results are mixed. She answers correctly that the cause of the seasons is “the earth’s movement (revolve, rotate) and the tilt that puts certain areas in direct or indirect sunlight.” She also writes, correctly, that Earth is closer to the Sun in the winter, and that the Sun rises in the northeast in summer and in the southeast in winter. However, she erroneously draws an oval (elliptical) to represent a top-view of Earths’ orbit, with the Sun at the exact center of the oval. She also incorrectly marks that the Sun sets in the southwest in summer and northwest in winter.

Martha’s students have relatively lower scores on the test at the beginning of the module than do Sharron’s students (Table 1). Table 3 presents data on types of responses to an item about the orbit of Earth about the Sun. On the pre-test, 8 students draw Earth in a circular orbit about the Sun; this increases to 11 by the end of the module. Additionally, all students’ pre-tests indicate that Earth was nearer the Sun in summer; on the post-test, four students correctly select winter instead.

The responses about the cause of the seasons are quite interesting for Martha’s class. On the pre-test, 7 students mention the distance between Earth and the Sun, and 3 students do not answer or write that they do not know. Other responses vary, including statements about clouds, other planets, or shadows. By the post-test, eleven students do not answer or write that they do not know. Of those who do answer, one student writes that the “slant” of Earth was the cause, one student describes the rotation and orbit of Earth, and one student mentions the Moon as cause of the seasons.

Martha’s students have higher scores on the post-test than the pre-test. Some responses show more homogeneity among the drawings, but the responses are more correct. The students’ drawings and explanations do not appear very similar to Martha’s responses on the test, and students’ responses become more scientifically accurate than Martha’s answers.

Discussion

While many children and their teachers hold naïve conceptions about natural phenomena, it is not known whether teachers' naïve conceptions serve as a boundary condition for their students' learning. In this study, I examined possible relationships between changes in students' conceptions and their teachers' conceptions, attitudes, and understanding of conceptual change instruction.

Overall, the findings provide tentative support for such a relationship between teachers' knowledge, their attitudes and beliefs about science teaching, and their students' learning. Students in Sharron's class scored lower on the post-test than on the pre-test. Furthermore, on the post-test, Sharron's students produced more homogeneous responses, including use of language similar to Sharron's. This may be related to Sharron's replacement idea of teaching, in which students should learn what is right and forget what is wrong. She knows that students want to "be right," and she tries to help them be so. Unfortunately, because Sharron had misunderstandings of the content at the outset, she may have encouraged students to accept her misunderstandings as the appropriate answer. In contrast, Martha's students began with less informed views than did Sharron's students. By the end of the module, Martha's students transitioned to more informed views. Furthermore, the students' responses were not always similar to Martha's initial answers. This may be related to Martha's attitude toward science teaching and her awareness of conceptual change instructional strategies.

This study yields initial evidence that incomplete understanding on the part of the classroom teacher may not, by itself, lead students to develop scientifically inaccurate conceptions. The findings show that the teachers' conceptual understanding is an important predictor of changes in their students' conceptions. Furthermore, the findings also suggest that teachers' attitudes or instructional approach can serve as mediators of the relationship between teachers' conceptions and their students' learning. It may be that teachers who promote rote learning lead students to repeat the teachers' conceptions—whether correct or incorrect—on assessments. Therefore, teachers with higher pedagogical knowledge or with more positive attitudes toward science and science teaching may have classes with more accurate conceptions, although with greater variation in students' responses. Additional research is needed to test this conjecture.

Limitations and Implications for Future Research

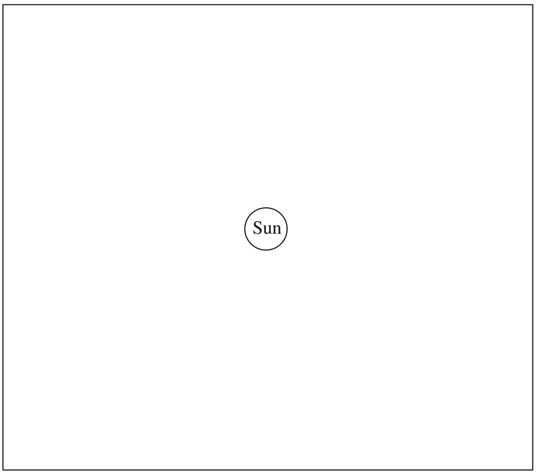
While this study does show some promise, it also has important limitations that will warrant further study. For example, the research took place with only two teachers in the same school. Making a broader assertion about the relationship between student learning and their teachers' knowledge of and use of conceptual change instruction would require a larger and more extensive data set. Thus, further research is needed to examine this supposition with larger numbers of teachers and across contexts. For example, a follow-up study of the proposed relationships among teachers' conceptual understanding of the content, their understanding of conceptual change instruction, and student learning could recruit greater numbers of teachers across a variety of settings. This would allow a more rigorous examination of the moderating effects of teachers' understanding of conceptual change.

A second limitation was that I could not account for differences in the teachers' use of the curriculum itself. Instead, the study relied on interviews with the teachers about their instruction and instructional decisions. Future research could also address teachers' instruction, such as through observations of their practice (e.g., Century et al. 2010; Thadani et al. 2009), to examine the mediating effect of enacted curriculum on student learning outcomes.

In conclusion, while increasing elementary teachers' scientific understanding of natural phenomena is valuable, increasing teachers' understanding of appropriate pedagogies that promote conceptual change may be just as important. While not ignoring the value of content knowledge, teacher professional development programs may need to focus primarily on understanding and applying pedagogical principles for conceptual change as an essential part of supporting students' conceptual development.

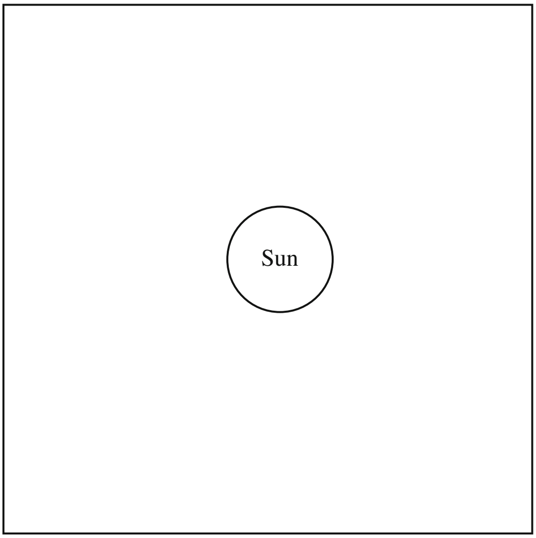
Appendix 1: Open-ended items from student and teacher conceptual assessment

1. The picture below shows the Sun. Please draw a top view of the path you think the Earth makes as it moves over the course of 1 year.



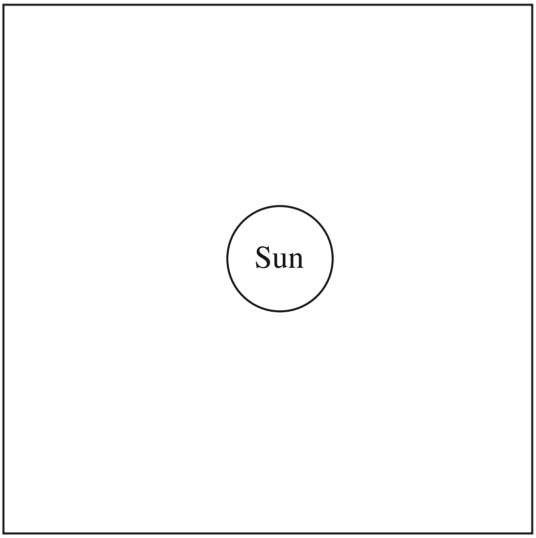
(top view of the Sun's orbit)

2. The picture below shows the Sun. Please draw a side view of where you think Earth is in the winter.



(side view in winter)

3. The picture below shows the Sun. Please draw a side view of where you think Earth is in the summer.



(side view in summer)

4. Of the two pictures you drew above (for Questions 2 and 3), when is Earth closer to the Sun?
5. Please explain what causes the seasons.

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