Research in Science Education (2005) 35: 245–268
DOI: 10.1007/s11165-005-3176-8

How do Elementary Teachers Compensate for Incomplete Science Content Knowledge?

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Abstract

The purpose of this study was to describe how three primary teachers attempted to overcome incomplete content knowledge when teaching an astronomy unit. Daily observations of science activities were videotaped and transcribed from each classroom to determine the influences on the changes in teacher and student ideas of astronomy. Teachers' ideas were triggered toward the more scientific by classroom interactions. Influences on the experienced teachers' ideas were questions raised by the students, or conceptions students held of the content. Experienced teachers planned to elicit and address student ideas, and so were triggered to improve their understanding of the astronomy.

It is common knowledge that students bring their own ideas about science to science classrooms (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyburg, 1985; Piaget, 1929). Children's ideas influence what they gain from instruction. Additionally, teachers have their own ideas of science content that may not reflect accurate conceptions (Neale, Smith, & Johnson, 1900; Stoddart, Connell, Stofflett, & Peck, 1993). Elementary teachers are typically specialists in literacy and not science (e.g., Akerson, Flick, & Lederman, 2000; Flick, 1995), thus it is not surprising that their knowledge of science content can be incomplete. Elementary teachers may lack confidence in their abilities to teach science because of incomplete content knowledge (Akerson & Flanigan, 2000; Borko, 1993; Dickinson, Burns, Hagen, & Locker, 1997; Smith & Neale, 1989). Even elementary science enthusiasts, who effectively teach concepts for which they have sufficient background knowledge, have difficulty teaching other science concepts because of incomplete content knowledge (Abell & Roth, 1992). Typically, elementary teachers take introductory science courses in their teacher preparation programs, yet those courses often do not suit their needs or interests and do not contribute to their knowledge of science content (Dickinson & Flick, 1996; Tobias, 1992). Thus, elementary teacher conceptions of science may be incomplete, and university coursework may not help to improve their science knowledge.

Harlen (1997) found that elementary teachers used coping strategies that enabled them to teach science despite incomplete knowledge of the content. These strategies included:

(a) teaching as little of the subject as possible;
(b) teaching more biology vs. physical science;

(c) placing reliance on outside-developed lessons like kits, texts, and step-by-step work cards;
(d) emphasising expository teaching and underplaying discussions;
(e) avoiding all but the simplest hands-on activities; and
(f) seeking outside experts and colleagues.

But what of the elementary teachers who enjoy teaching science on a daily basis, who strive to include hands-on activities, and who develop their own lessons specific to their students' needs? Perhaps these teachers use other coping strategies that enable them to influence their students' understandings, while enhancing their own conceptions. Jones, Carter, and Rua (1999) found that children's science concepts can be an influence on preservice science teacher knowledge. Thus, what children know can influence what preservice teachers know. But from where does that knowledge develop, and does it also influence inservice science teacher knowledge? The purpose of the current study was to explore classroom triggers that influenced teachers to compensate for incomplete knowledge of astronomy during an 8-week unit. The specific research question was: How do primary teachers seek to compensate for incomplete content knowledge when teaching science? Are there classroom triggers that influence teachers to produce knowledge that arise from their teaching?

Theoretical Framework

There is reason to believe that the science learning that takes place in a classroom is dependent on the ways that teachers and students talk about science (Lemke, 1990). Lemke contends that students will pay attention and engage in talk in science class when the talk is characterised as everyday language rather than official "science talk." Students learn both about science, and science content itself, through classroom discourse. Reasoning is a social process between teachers and students, and if reasoning is a goal of science education, it is logical to attend to classroom discourse to decipher that scientific reasoning (Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993). Thus, the teachers and students in the classroom engage in interactions that enable them to negotiate meaning, or "co-construct" knowledge through their exchanges.

Cazden (2001) also maintains that students learn through talk with the teacher as well as talk among themselves. She has found that talk in the classroom is where meaning is socially constructed among class members. She differentiates between authoritative discourse, in which teachers and students use academic language to describe and discuss ideas about phenomena, and exploratory talk which has no answers intact, and allows the use of students' own terminology as part of the discourse. Edwards (1993) contends that even though it is difficult to use children's discourse as keys to their conceptual development, analysis of that discourse can give insights into their understandings of content. Discourse analysis focuses on ways understandings are formulated, and instances that trigger those formulations.

Analysis of classroom interactions can also be used to identify triggers to teacher construction of knowledge.

Cortazzi (1993) describes five sets of assumptions that are consistent within a constructivist framework that points to the importance of analysis of classroom discourse for meaning making:

1. understanding as a constructive process;
2. meaning is actively interpreted;
3. understanding occurs concurrently with information input and processing;
4. understanding activates and uses presuppositions in the form of previous experiences, beliefs and attitudes, motivations and goals;
5. understanders and producers use information from events, the situation or context, presuppositions, and existing schemata flexibly and strategically. (pp. 67–68)

Thus meaning is ascribed and constructed to science content and processes through discourse between students and teachers. It makes sense, therefore, to look at the discourse in the classroom as an indicator of understanding, and for where those prompts for understanding may be.

Edwards and Mercer (1987) describe the idea that it is through the discourse in the classroom that understanding, for both the teacher and the students, develops. Their description of general classroom discourse goes through the format of IRF, or *initiation*, in which teachers ask a question about a concept, the student *responds*, and then the teacher provides *feedback*. It is presumably through this feedback that students change their views. The assumption that the teacher and students are constructing common knowledge may itself influence student understanding, though the difference of power between student and teacher may affect that understanding and the discourse.

Gallas (1995) uses "science talks" with her elementary students during which she seeks to remove the difference in power between student and teacher by allowing the students to control the talk. She states that a hands-on activity approach to science is not enough, that there must be discourse surrounding the content, and that this is where the meaning is ascribed. True dialogue around a science concept is where the teacher does not have the "right" answer, but in which all members of the community are searching for answers and explanations. She maintains that through these talks both she and her students develop understandings of science.

To develop these understandings through discourse, the more experienced person (usually the teacher) helps the less experienced person (usually the student) complete tasks they would be unable to complete on their own. Vygotsky (1978, 1986) describes this metaphor of scaffolding as the "zone of proximal development." The scaffolding depends on social interaction between the more experienced and less experienced persons. The social interaction allows the experienced person to provide examples that connect to previous understandings, ask questions that trigger further thought about the idea by the less experienced person, and allows them both to talk and share ideas about the phenomenon. It seems that teachers, who are generally more experienced persons, use scaffolding through discourse and interaction with their students to help their students develop better understandings of concepts and content. Palinscar (1986) claims that classroom dialogue has a strong role in providing scaffolded instruction. She claims that an effective way to use scaffolded instruction is through reciprocal teaching which is a dialogue between teachers and students where participants take turns assuming the role of the teacher. In this way the dialogue between both can serve to teach both participants. This "co-construction" of knowledge can trigger development of understanding in both teachers and students. Palinscar (1998) continues to emphasise the importance of considering the contexts in which scaffolding occurs, and the relationship of scaffolding and effective teaching as triggers for understanding content.

Because there is much interaction in classrooms, and there is such strong evidence that social interaction is where meaning is made, this paper focuses on discourse and interaction between teacher and students. Classroom interactions in two Grade 2 classrooms were analysed for instances that triggered the need to overcome incomplete content knowledge by teachers.

Research Methodology, Design, and Procedures

Two Grade 2 teachers and one teacher intern were selected from 61 elementary teachers in a suburban northwest community in the United States to participate in a study tracking triggers toward improved content knowledge of astronomy. All names included are pseudonyms. The two experienced second grade teachers were the only ones who met the following criteria:

(1) delivery of the same science content during the course of the study;
(2) a minimum of five years of experience, enough to assure development as an experienced teachers; and
(3) science was taught as a separate subject.

The two experienced teachers taught in the same school and planned the unit together. The teacher intern happened to be teaching in one of the teachers' classrooms at the time of the study, and was largely responsible for science instruction at that time, thus she was included in the study.

The first teacher, Ms Buyse, had 24 years of teaching experience. She enjoyed teaching reading and language arts, and held a masters degree in early childhood education. She believed that science was an important part of the elementary classroom because it helped students to explore their own world. The second teacher, Ms Richardson, had ten years of elementary teaching experience. She also had a master's degree in early childhood education and a strong interest in language arts and reading. She believed that science was important in maintaining primary students' interest in their learning. Ms Stiles was an intern teacher in Ms Richardson's class, and was earning a Master of Arts in Elementary Education. This was the first time that she had ever taught science. She was included as a participant because she was an integral part of the astronomy instruction in the class.

Ms Buyse and Ms Richardson designed their own astronomy curriculum, pulling from a variety of sources to develop a unit to fit their own students' needs. Because they were teaching at the same school, they created the unit together, and used their district Benchmarks which were adapted from the national *Benchmarks for Science Literacy* (American Association for the Advancement of Science (AAAS), 1993) to ensure their students would meet the required goals. Ms Stiles taught from the unit when she taught in Ms Richardson's room. However, the approach each teacher took differed, and a description of these different classroom strategies follows in the Teaching Approaches section.

Data Collection

In-depth classroom observations allowed the researcher to search for classroom influences that encouraged the teachers to seek to improve their knowledge of astronomy. The role of the researcher was as an observer, not as an advisor for any of the lessons.

All science lessons (approximately 40 hours) in each classroom during the 8-week units were observed and videotaped for transcription. The transcripts were coded to find instances of triggers for the teachers to overcome weaknesses in science conceptions. These transcriptions were also used to build a picture of instruction in each classroom. The videotape focused on whole class instruction as well as small group and teacher–student dyads. The video camera was placed at the back of the classroom to remain unobtrusive during lessons.

Data Analysis

Classroom observations and videotape transcriptions were used to determine triggers toward change of teacher understandings of astronomy. An interpretive approach was used as the researcher reviewed the transcriptions for patterns of influence on teacher knowledge in classroom interactions. The researcher looked for triggers for improving content knowledge for teachers during classroom interactions. These instances were reviewed and specific triggers were noted. Patterns of these instances were noted to see how teachers compensated for incomplete content knowledge. The researcher identified these as triggers to improve knowledge. The notes served as early codes for influences, such as "teacher influenced by student question," which was later changed to "student question." The data was further reduced with a second reading that sought patterns of classroom influence on each teacher individually.

Finally, the researcher discounted the data (Taylor & Bogdan, 1984). In this process data were reviewed to see whether other interpretations could be made of the results. Counterexamples were sought to ensure the validity of interpretation of the inferences made from the data.

Results

The sections below describe the teaching approaches that took place in each classroom. These sections are followed by ways each teacher compensated for incomplete content knowledge.

Teaching Approaches

Brief descriptions of teaching approaches that took place in each classroom during astronomy instruction are provided. These strategies were determined through triangulation of daily classroom observations and videotaped transcriptions.

Classroom One

Ms Buyse taught science every day. The major task for her students was to select an individual area of interest in astronomy, read about that topic in a variety of sources, take notes about information that interested them enough to read about and write a report on the topic. Students were allowed to select any topic that interested them, from black holes to specific planets even if another student had already selected the same topic. Ms Buyse delivered numerous hands-on lessons to the students, having them strive to conceptualise motions of planets, orbits, and the building of representative models.

Ms Buyse's typical teaching sequence can be described as a revisiting of ideas. She began each lesson with an initial open-ended question to gather student ideas about a concept. Students readily responded to her question, sharing their own ideas about the science content. She used probing questions to help her determine how many students shared the ideas elicited in her classroom. Probing questions included questions such as "Can you tell me why you think that?" or "Can you tell me more about that idea?" These probes were designed to gather more information, not to lead students to answer in a particular way. As the students worked independently, the teacher circulated from student to student. She raised the same initial open-ended question to understand individual student ideas. The teacher dropped the line of questioning when the discussion carried on to abstract concepts, and then revisited the ideas later. She used probing questions to check how students were interpreting her initial questions. She sometimes allowed the idea to remain open, asked the student to continue thinking about the point, and then returned to the point later with the same student. On occasion she engaged in explicitly teaching the content related to student ideas. She explicitly taught by one of five strategies:

(a) Lesson Development, or developing a lesson specifically designed to address student ideas;
(b) Demonstration, wherein she demonstrated a concept using concrete objects;
(c) Literature Connection that consisted of reading a non-fiction children's book to address specific ideas;

(d) Explanation where she explained a concept without using manipulatives or visual aids; or
(e) Scaffolding where she linked new ideas to old ideas by finding something familiar to the students and using that as a connection to the new idea.

An example of an explicit lesson to change student ideas will be shared later. Following this instruction, Ms Buyse again raised the initial question in a whole group setting, and student responses were noted. If Ms Buyse determined students still had faulty understandings she often raised the question again in small group dyads.

Classroom Two

Ms Richardson also taught science every day. Students in Ms Richardson's class selected an individual area of interest to study from a list prepared by Ms Richardson. Each student read about his or her topic, took notes, organised the notes, and wrote a report on the topic. No two students were allowed to study the same topic, with the exception of two "low" students who were assigned to work together. Ms Richardson required one person to study each planet. If no one wanted to study a particular planet she waited until someone volunteered. Ms Richardson told students "you can study any topic and learn a lot about it. If you have free time you can always read about another topic that interests you."

In addition to time for individual research, students were treated to an almost daily hands-on activity. Ms Stiles, the intern, exclusively delivered the hands-on activities. Topics for the activities were given to Ms Stiles by Ms Richardson, and Ms Richardson gave Ms Stiles teaching advice, though Ms Stiles did not always follow it. Ms Stiles found additional activities to address various concepts in different resource books and re-designed them to fit a style of lesson planning given her from her elementary education department. The hands-on activities covered topics such as: gravity, action/reaction, rocket thrust, phases of the Moon, the surface of the Moon, food dehydration, and constellations. Ms Richardson often debriefed the activities with the class at the conclusion. Ms Stiles initially did not like the interruptions but eventually began to conduct the debriefs similarly to Ms Richardson.

Ms Richardson's favoured mode of instruction was the use of discussion. She enjoyed having hands-on activities but assigned those activities to Ms Stiles. Ms Richardson was the person who most often conducted whole class, small group, and teacher/student dyad discussions. She reported that she used much questioning to gather students' understandings.

Instructional sequence, Ms Richardson

Ms Richardson's typical teaching sequence proceeded similarly for whole group and teacher/student dyad discussions. Ms Richardson began each discussion with an initial open-ended question that elicited children's thoughts about different concepts. In general, all student responses were accepted. She also used probing questions to note the depth of understanding of ideas. Ms Richardson responded to children's ideas using one of three strategies:

(a) Explanation, or providing accurate information by telling them;
(b) Literature Connection, by reading a non-fiction book to address ideas; and
(c) Activity Debrief where she held a discussion following the intern's presentation of an activity.

In all cases Ms Richardson attempted to build on prior experiences by connecting the new idea to an already known idea, or to an experience she was reasonably sure students would have had. Unlike Ms Buyse, the ideas were not revisited, nor were the same ideas raised in small groups and then again in large groups and back to small groups. However, Ms Richardson's instruction may not have proceeded in a fashion that was typical for her because the intern teacher taught in her room.

Instructional sequence, Ms Stiles

Ms Stiles' typical teaching sequence consisted of an initial open-ended question that was presented to the whole group. Students readily responded to the prompt. Occasionally Ms Stiles was unsure of how to respond to the students' statements and seemed surprised at their statements.

Following the initial discussion, Ms Stiles broke the students into smaller groups, calling them "research teams." She assigned roles to each student, and they conducted investigations in small groups. While they were conducting investigations she circulated through the room, keeping students on task and verifying they were following procedures.

Following the activity Ms Stiles asked students to meet together as a whole class to discuss their findings from the activity. She always asked the students "Why do you think we did this activity?" and "What did you learn from this activity?" Ms Stiles asked students to make written records in the way of charts, drawings, and writings regarding the activities and the meanings they made from them.

During her discussions, both before and after the activity, Ms Stiles believed it was her questioning skills that prompted unusual student responses. She demonstrated no awareness that students may have alternative conceptions for scientific ideas. She rephrased her questions in ways she hoped would make them more understandable to the students. Occasionally she ignored students' responses, and sometimes she continued her questioning until she obtained the "correct" response.

How Do Teachers Cope with Incomplete Content Knowledge?

An analysis of classroom interaction through transcripts of classroom lessons allowed the researcher to discern the ways the teachers sought to improve their students' understandings of astronomy, despite their own incomplete content knowledge. A description of these influences follows below. Each classroom vignette has been titled to allow easy reference to various episodes (Cazden, 2001).

Students, Classroom One

Ms Buyse influenced her students' knowledge of astronomy in several ways. She described her teaching of astronomy, and indeed, of any science concept, as helping students reconcile "kid language" with adult language – to help them interpret what adults mean by their use of words, compared to what children mean when using the same words. First, by eliciting their ideas about astronomy, she was able to understand their naïve views, and thus plan lessons to specifically address those ideas. By eliciting their ideas, she was able to recognise "holes" in her own knowledge of astronomy content. For example, in the exchange below a student was talking to the teacher about her topic – the Moon. She was explaining her views of how the Moon "caused" the night:

Day and Night Part 1

1. Kira: You know, the Moon switches places with the Earth.
2. Ms Buyse: It does?
3. Katy: It does that to make day and night.
4. Ms Buyse: What do you mean it switches places with the Earth?
5. Katy: Like here it is, closer to the Sun (she is holding two pencils as props). It moves from side over, and then it switches.
6. Ms Buyse: That is an interesting way to describe it.
7. Katy: That is how it makes day and night.
8. Ms Buyse: All right. You think night has something to do with the Moon.
9. Katy: When the Moon is in the sky the Sun shines and gives it light, then it shines on the Earth.
10. Ms Buyse: Have you ever seen the Moon in the sky during the day?
11. Katy: Yeah, when it is turning nighttime.
12. Ms Buyse: Uh huh. You think of that some more. And soon we will use some balls of clay to talk about how the Moon, Sun, and the Earth work together and how it makes day and night, and we'll see what you think about that. You can explain it to me then how you think the Sun and the Moon switch places, and then I can explain it to you how I think they work.

The exchange illustrates several points about Ms Buyse's teaching. First, it shows her respect for her students' ideas. Ms Buyse was respectful of the student's explanation, and listened fully, even asking questions to further clarify Katy's ideas (Utterances 4, 10). Second, it shows she is seeking to understand what Katy means by "switches" (Utterance 4). Third, it illustrates her emphasis on allowing students to grapple with their own ideas – she often spoke the words "Think about that some more and then we will share what we think again" (Utterance 12). And finally, it shows how she uses children's ideas as starting points for future lessons (Utterance 12), though the future lesson could have simply asked students to observe the Moon during the day to realise that yes, it sometimes did appear in the day.

As a result of this lesson, the teacher adjusted her lesson plans to have students use models of the Earth, Moon, and Sun, to explore their views of their relationships later that same week. This activity allowed Katy to confront her ideas again, as well as allowed her classmates to think about the same topic. The teacher taped inflated balloons in the middle of tables to serve as models of the Moon, and the students used pom poms as models of the Earth and Moon to trace their movements around the Sun to figure out what is the "cause" of day and night:

Day and Night Part 2

1. Ms Buyse: Look at how your Earth is moving around the Sun – is the same part always facing the Sun?
2. Student: No – part of it is facing away from the Sun when it spins.
3. Ms Buyse: Explain what you think it might look on the side of the Earth that is not facing the Sun.
4. Katy: It would be dark!
5. Ms Buyse: What makes you say that?
6. Katy: Well, the Sun gives light, but if you aren't looking at the Sun you aren't getting light. And the Moon is on the same side as the Earth! So you get night if your part of the world isn't looking at the Sun. And these people (pointing to the side facing the Sun) are in the day!
7. Ms Buyse: Can everyone see what Katy is saying?
8. Sam: Yeah, if you're on the side facing the Sun, you're getting day. If not, you're getting night.

Ms Buyse planned the lesson specifically to address student ideas, and raised a question to help all students conceptualise an accurate idea (Utterance 1). Her subsequent comments continue asking for student ideas (Utterances 3, 5, 7).

A few days later Ms Buyse again chatted with Katy regarding her views of the Moon's role in day and night:

Day and Night Part 3

1. Ms Buyse: How is your work on the Moon going Katy?
2. Katy: Good. I know lots about the Moon now.
3. Ms Buyse: Great! What new can you tell me?
4. Katy: Well, I saw the Moon this morning. And it was light out. But now I know the Moon doesn't cause night. It is how we are looking at the Sun that causes day. The Moon can come out at day or night!

Utterance 4 shows that Katy has revised her thinking regarding day and night. It is apparent that Katy's revised thinking was due to her observation of the Moon, not solely the modeled lesson. The entire series of exchanges shows typical teaching patterns and emphases for Ms Buyse – she focused on student ideas in both whole group and teacher–student dyads, and uses those ideas to plan lessons to confront and improve thinking. Occasionally those plans were to read a non-fiction book to illustrate scientific ideas instead of provide an activity. Consider the following exchange with a student studying the stars:

Twinkling Stars Part 1

1. Kelsey: Stars twinkle. That means they blink on and off.
2. Ms Buyse: Oh – is that what happens?
3. Kelsey: Yeah – they blink.

In Utterance 1 Kelsey shared her view of what causes the stars to twinkle. Ms Buyse listened to that statement, and two days later Ms Buyse read a book about stars written by Isaac Asimov to the class. She stated to the researcher that she often used non-fiction tradebooks to clarify content when she was unsure of it herself. Indeed, she admitted to not understanding why the stars seemed to twinkle, and that is what prompted her to seek the book. Below is a typical pattern showing discussion of ideas during the reading:

Twinkling Stars Part 2

1. Ms Buyse: (Begins reading.) Do you think stars twinkle? Answer yes or no.
2. Students: (Most say yes, a few say no.)
3. Ms Buyse: That's the way it is best, if we don't all agree so we have time for discovery (continues reading). Are the stars gone during the day? Why can't we see the stars?
4. Student: Because the Sun is brighter.
5. Maggie: The Sun is closer and it is bright and it makes it so you can't see the stars.
6. Ms Buyse: Right – the Sun's bright light is too bright to let us see the stars that are farther away. Are they really little?
7. Students: No.
8. Ms Buyse: They are really big, aren't they? (Continues reading.) Do you know what optical means? Point to the part of your body that means 'optical.' Right – eyes. When you get your eyes looked at you go to an optician. An optical illusion is an illusion played on your eyes. Or a trick played on your eyes. Twinkling is an optical illusion (continues reading). It is because we see the stars through our atmosphere. Who can explain what the problem is with the telescope? Jane.
9. Jane: Well, it makes it look like the stars are brighter, but it also makes the twinkling look brighter.
10. Ms Buyse: Okay. Does that match with what other people are thinking? Does anyone have any different ideas? (No one did – all agreed.)

The exchange shows that Ms Buyse listened to student views about science concepts they were studying, and planned activities, or found literature to help make those viewpoints more scientific. She continued raising those views in both whole class and small group settings to reinforce new ideas and to allow students to focus on their thinking in different settings. However, while she did continue to focus on students' ideas, she sometimes did abandon their ideas and "move ahead." For instance, in the above exchange on twinkling, Utterance 3 shows she simply continues on with her reading rather than explore those different ideas.

Influence on Ms Buyse's views

Ms Buyse was triggered to improve her astronomy content as a result of teaching the unit to her students. Patterns in classroom transcripts show that she was influenced in three main ways:
(1) by student questions/comments;
(2) by the need to address student ideas; and
(3) by listening to students share results of their research.

To reiterate, Ms Buyse's self-described philosophy of science teaching was to translate adult views of the world to be accessible to children. Her philosophy is in-line with Shulman's (1986, 1987) theory of pedagogical content knowledge, or finding ways to address student ideas through different representation of content. To be able to represent that content she needed to understand it first. Thus, student ideas triggered Ms Buyse to compensate for her incomplete knowledge of astronomy.

The following whole-class exchange illustrates how student questions triggered Ms Buyse to read about a topic to compensate for her incomplete content knowledge.

Galaxies Part 1

1. Brian: What's a galaxy?
2. Ms Buyse: What is a galaxy? We haven't talked much about that yet. What is a galaxy? That is a good question. I think we should talk about it a bit. Maggie, what do you think a galaxy is?
3. Maggie: It's a bunch of stars, and there is a hole in the middle.
4. Ms Buyse: I see. Okay. Krista, what do you think?
5. Krista: It's a group of stars.
6. Ms Buyse: Okay. (Student brings a picture.) Oh, and here is a picture of a galaxy. Very good. Any other comments about galaxies? I will find something on galaxies and I will read it out loud to you. To give you a little more detail about galaxies because I am not sure about them myself.

The student's question in Utterance 1 prompted a discussion of students' ideas about galaxies. The teacher elicited several students' definitions, and then admitted she needed to know more about galaxies to be able to tell them what they wanted to know (Utterance 6). She asked the students work independently on their own research topics while Ms Buyse sought information on galaxies in the non-fiction classroom library. Ms Buyse called them back together toward the end of the period and read some information to the class:

Galaxies Part 2

1. Ms Buyse: I found something on galaxies. If you will listen I will read it to you. It is a brief definition instead of a long, drawn-out definition. It says "Our planet Earth is located within a huge star group called the Milky Way Galaxy. It has more than 100 million stars. That is 20 stars for each man, woman, and child on Earth. Our Milky Way Galaxy spins around."

2. Students: Wow!
3. Ms Buyse: Yes! (Continues reading.) "It also flies through space like a giant Frisbee. It goes a speed of a million miles an hour. Here is a picture of our galaxy. Like many galaxies it is a spiral." It really does look like a pancake, a spiral, it is spinning through space. If our Earth and our Sun are part of the Milky Way Galaxy, and the Milky Way Galaxy is flying through space then what are we doing?
4. Students: Flying through space.
5. Ms Buyse: We absolutely are. It is amazing.

Thus, through Utterances 1 and 3 we see that Ms Buyse has tried to improve her and her students' knowledge of galaxies. It is not clear how much the students have actually gained in their conceptual understandings of galaxies, but their questions did trigger Ms Buyse to research the concept so she could help them have better understandings, thus focusing on construction of common knowledge in the classroom.

In the next example, Ms Buyse was triggered to consider her content knowledge of astronomy through discussions with her students. However, the discussions did not necessarily need to include student questions, only evidence that the student understanding was not close to scientific. Thus, Ms Buyse was triggered to improve her understanding so she could better translate that content so student understandings could improve. Day and Night Part 1 is an illustration of a conversation between Ms Buyse and a student that prompted Ms Buyse to improve her understanding of why there is day and night. The student's views (Utterances 1, 3, and 5) were interesting, yet obviously not scientific. Ms Buyse took the opportunity to learn more about the relationship of the Earth, Moon, and Sun through her own research. She used methods that would translate more scientific views to her students, resulting in Day and Night Part 2. Her check of student understanding in Day and Night Part 3 enabled her to know whether the student had a better conception (e.g., Osborne, 1991, Model 3) following the activity.

Another way Ms Buyse was triggered to compensate for her incomplete content knowledge of astronomy was simply by listening to students share their research results with her. Thus, the students were put in the role of the teacher, similar in a sense to reciprocal teaching (Palinscar, 1986). The following exchange is such an example:

Uranus' Moons

1. Ms Buyse: Hi Holly, how are you doing?
2. Holly: Guess what? Uranus' moons are named after Shakespearean characters, like Juliet.
3. Ms Buyse: Oh! That's beautiful, I didn't know that. How many moons does it have?
4. Holly: Twenty.
5. Ms Buyse: Wow! What interesting things you have learned. And now I have learned them too!

Ms Buyse showed her students the value of what they were learning by allowing them to teach her new things (Utterance 2). She also shared with them that she was still learning, and they played a role in her knowledge (Utterance 5).

Students, Classroom Two

Students in Classroom Two received instruction from both Ms Richardson and the intern, Ms Stiles. They learned from discussions, stories, and debriefings of lessons from Ms Richardson and activities led by Ms Stiles.

Ms Richardson, like Ms Buyse, was adept at getting students to talk about their ideas and the meanings they were making from their research and from activities (that were led by Ms Stiles). She helped students relate new ideas to their own experiences to scaffold them to new understandings. The exchange below with an English as a second language student shows how she used teacher–student dyads to help students make sense of the independent research they were conducting. Prior to the exchange she asked Marisol to think about what she would feel if she were closer to the Sun, and then asked her to relate that to how she feels next to a heat source:

Distance from the Sun

1. Ms Richardson: Think about a fire. If you are right next to it it is really hot, but if you are far away what does it get?
2. Marisol: It feels colder because you aren't as close.
3. Ms Richardson: So if you were very far away from the Sun, what do you think is going to happen?
4. Marisol: It will get colder.
5. Ms Richardson: So if the planets are so close it might be too what?
6. Marisol: Hot.
7. Ms Richardson: And if it is one of the planets out here it might be too what?
8. Marisol: Cool.
9. Ms Richardson: But we're just great. We have it just right. What do you think the Sun helps do on Earth?
10. Marisol: Umm if there wasn't any Sun it would be dark.
11. Ms Richardson: Yeah. And what else?
12. Marisol: It would be cold.

Utterances 2–4 show Ms Richardson providing a context for Marisol's understanding of the relative temperatures of the planets as a result of distance from the Sun (she does not speak about heat trapped by atmosphere, however). Utterances 9–11 illustrate her attempts to help Marisol apply the information. Ms Richardson also used non-fiction children's literature to help her students develop better understandings of the astronomy content, as well as to explore their ideas. In the exchange below Ms Richardson reads aloud a book about the solar system while having students share their ideas and justify their thinking:

Floating Saturn

1. Ms Richardson: (Reading a non-fiction book to the group about planets in the solar system.) What are the names of the planets?
2. Students: (Stated the names of the planets in order from the Sun.)
3. Ms Richardson: Oh, good. You are really getting this. Why is it interesting to tell us that Saturn can float?
4. Alison: Because it might be made of something special.
5. Ms Richardson: Oh – she is on the right track. Roy, what do you think?
6. Roy: It's a gas.
7. Ms Richardson: You got it, Roy. It is a giant gas planet. This particular gas can float. But we could never do that because we couldn't put it in water! (Continues reading.)

The following exchanges illustrate how students learned through the activities presented by Ms Stiles, and then how Ms Richardson followed up on those exchanges to reinforce ideas. First, Ms Stiles taught a hands-on lesson about gravity to the students. Though her own conceptions in this area were weak (i.e., she stated that gravity was a force that pushed on the Earth from the outside) the activity still helped students develop more accurate views than they previously held, possibly reinforced by the debrief that Ms Richardson held after the lesson. Students were instructed to drop a rock and a crumpled piece of paper at the same time and height and record which hit the ground first, and then a crumpled and flat piece of paper and do a similar comparison. Below is the discussion following the activity led by Ms Richardson:

Gravity on the Earth

1. Ms Richardson: What happened? You had crumpled paper and flat paper. You dropped them. Last time the two things landed at the same time. Is that what happened this time? (Chorus of No!!!) Jacob?
2. Jacob: Well, the flat one is pulled out so it floats through the air. The air pushes it up because it is flat. The round one can't float because it is all crumpled up and it goes straight down.
3. Ms Richardson: Okay – so flatness was making the paper float. Michele, what else?
4. Michele: The crumpled one pushed less air out of the way.
5. Ms Richardson: These are such wonderful ideas. Ericka?
6. Ericka: I didn't think about that really. I thought that the paper that wasn't crumpled didn't have the weight in the same place. The weight in the squished one was all in one spot.
7. Travis: The crumpled one caught the air. Air couldn't get out, so it went down.
8. Stephanie: The flat one is more like an airplane.
9. Nava: It's a thing with no holes.
10. Eric: It's like a parachute.

11. Ms Richardson: You have some excellent ideas. And it does have something to do with the crumpled one not being able to catch as much air, and the flat one having more air pushing on it. And a little bit with the weight shifted because it has something to do with the air. Now I have a question for you. We talked about the shape being really important here. The air gets caught on the big flat one pushing it up, but not on the little crumpled one. Go back to the experiment with the rock. What about that?
12. Student: They were both the same size!
13. Ms Richardson: Right – the rock and crumpled paper almost always hit at the same time, and they were the same size. Why would these two have landed together? We are talking about a piece of paper and a rock. Talk in your tables and come up with one reason.

The discussion shows how Ms Richardson debriefed activities, and how she helped students explore their own explanations for what they observed in the investigation. She paraphrased ideas (i.e., Utterance 3), reinforced ideas (i.e., Utterance 11), asked them to consider many explanations (Utterance 6-1) and asked them to continue thinking about the questions in small groups (Utterance 13). Ms Richardson is acting like a "knowledge broker," reinforcing the students' reasoning toward improved conceptions.

The following day Ms Richardson continued following up on the ideas above when the topic was raised by a student in a small group:

Gravity on the Moon

1. Roy: Remember the experiment we did yesterday? On the Moon they did an experiment where they dropped a hammer and a feather and they both landed at the same time!
2. Ms Richardson: Interesting! How clever of you to relate that! I love that thinking, you are stretching your brain.
3. Jacob: Yeah, but a feather would get more air to push on it!
4. Roy: Yeah, but there is less air on the Moon.
5. Ms Richardson: Great thinking. Good job.

It is easy to note that Ms Richardson reinforced Roy's thinking, but not his knowledge (Utterances 2 and 5). She later related to the researcher that she was not sure if Roy was right or not, and did not want to reinforce incorrect understandings, but wanted to reinforce the thinking that had gone into his conception. She was not sure herself whether there was less air on the Moon, or no air on the Moon. She then read a non-fiction tradebook on gravity to clarify her own thinking.

Teachers, Classroom Two

Both teachers in the second classroom sought to improve their astronomy understandings. However, the triggers for compensating for their incomplete content knowledge were different for each teacher. For Ms Richardson, the experienced teacher, her own students' topics influenced her research and reading surrounding the topics. She planned to improve her knowledge in the topic areas they were studying. She also used current events to compensate for incomplete knowledge, and she shared the current events with her students. On the other hand, as a preservice teacher Ms Stiles was understandably more concerned about her teaching than students' learning, and did not use the students' knowledge as triggers for her own growth in understanding. She stated numerous times that she did not feel a purpose for fully understanding the content. However one lesson prompted her to verify her content knowledge prior to instruction to improve future lessons. A description of these triggers for improving understanding of content follows.

The student research topics served as triggers for Ms Richardson to read more about the content to improve her understanding. For example, the Gravity on the Moon episode influenced Ms Richardson to read tradebooks on gravity, Roy's research on the topic. She wanted to be able to conceptualise gravity on the Moon as well as the Earth.

An example of current events that improved Ms Richardson's views of astronomy is below. She wanted her students to have a clear understanding that everything in astronomy had not already been "figured out" and shared current events as often as she could:

Astronomy in the News

1. Ms Richardson: I would like to share something with you all from the newspaper. One, I love to read, and the other thing is that I like to know what is going on in the world. The first thing I read is that the "Mir gets a new generator and fresh astronaut – NASA delivers across the space centre." Sometimes when we study things we study things that happened in the past, but this that I will read you is happening this very day, and will be happening all during your life. (Begins reading.) Without the new generators they won't have enough oxygen. Why do they need oxygen?
2. Students: To breathe.
3. Ms Richardson: What will happen if they don't get enough oxygen?
4. Students: They die.
5. Ms Richardson: Well, yeah. It is pretty important that they get enough oxygen. (Finishes reading.) Just as I was saying to Ms Stiles the other day, it seems like since we have been studying astronomy there are lots of new kinds of developments occurring every day. So keep your eyes open and you might find something new. Keep watching for articles. I will hang this one up by the other ones. We will keep putting up new things for us all to read.

While Ms Richardson did ask students to share ideas about what she was reading (Utterances 1 and 3), it is easy to see these were closed questions that held "right" answers. It was also not clear whether the students fully comprehended what was being read, but it is certain that Ms Richardson gained ideas from the newspaper articles. Though ideas from newspaper articles may be deemed more trivial, she was still triggered to know more based on her own instructional needs.

Ms Stiles was not influenced by the students' research topics or by current events to improve her understandings of astronomy. She was concerned by her lack of understanding of astronomy content; to the point that she was delighted she had recently received an "A" in a university astronomy course, yet stated she did not feel she understood what she studied. As a preservice teacher with experienced teachers watching her instruction (her mentor teacher and supervisor), she was understandably concerned that her teaching "went well" and that the students did not "act out." As someone just learning to teach science, she underestimated the extent to which clarity of conceptual purpose was required, and as a new teacher, lacked the skills to deal with this. The following lesson describes her instruction on action and reaction (Newton's Third Law of Motion). Ms Stiles learned much from teaching this lesson, such as needing to have an understanding of the content she was to teach. Consider the following statement that started the lesson:

Newton's Third Law

1. Ms Stiles: Newton is called "The Father of Equality of Forces." He said that for every action, there is a reaction. That means that every time you do something, something else happens.

Ms Stiles' initial explanation was vague – it is not clear what she meant by "every time you do something, something else happens." There is no referent, nor example from which the students could develop an understanding. The lesson continued with Ms Stiles using two inflated balloons that she could push together and when let go they would push each other apart. In the exchange below you can note that Ms Stiles is unclear what she wants the students to focus on in their observations, and she then gets frustrated when they do not see what she wants them to see.

2. Ms Stiles: Okay – if I hold them like this and push (puts both balloons together) what will happen?
3. Will: Get bigger and flat.
4. Ms Stiles: What do you mean bigger – does more air come in?
5. Roy: No, the air gets squished and wants to come out, but it can't so it gets bigger and flatter.
6. Ms Stiles: Okay, I am going to make it really easy – I will just push this one. Now do they look the same?
7. Some students answer yes, some with no.
8. Ms Stiles: You mean they don't look the same to you?
9. Students: Not really.
10. Ms Stiles: Well if I keep pushing on them and let go what will happen?
11. Sarah: Drop to the ground?...
12. Ms Stiles releases the balloons.
13. Students: They shot apart!
14. Ms Stiles: If pushing them together was the action, what was the reaction?
15. Students: They dropped.

16. Ms Stiles: But they didn't – they shot out! Do you think that happens with everything?
17. Students: No.
18. Ms Stiles: But it has to happen with everything because they wouldn't have made it a law if it didn't!

Ms Stiles was very frustrated by the end of this segment (Utterances 16, 18). The students appeared to be trying to figure out what she was trying to get them to see, but they were not successful (e.g., Utterances 7, 11). She hoped her lesson would help her students learn, and she thought the demonstration would clearly show them the intended concept. However, Ms Stiles did not share a clear understanding of Newton's Third Law (Utterance 1), and did not translate the idea in a fashion that was attainable by these second grade students (e.g., Utterance 17). Ms Stiles demonstrated other examples of the law that were unfortunately also ineffective. She later asked students whether they understood what she was sharing, and the students simply stated "No." Ms Richardson then jumped into the lesson and simply asked students to go ahead and begin working on their individual research projects. Ms Stiles was visibly upset that she was not able to teach the Law to the second graders. At this point, as a new teacher who had not taught science before, she did not have enough content knowledge or pedagogical content knowledge to effectively teach this concept (Shulman, 1986, 1987).

Newton's Third Law is a difficult topic to teach, and is not a topic that is typical in a second grade curriculum. In fact, Ms Richardson asked Ms Stiles not to teach the topic because it was not developmentally appropriate for second graders. The topic was not raised again during the unit. However, on the following teaching day Ms Stiles was planning a lesson on orbits. To ensure she had a strong enough understanding of orbits, prior to teaching this lesson she read some non-fiction selections about orbits, and shared that she had done so with the students (Utterance 3):

Orbit Lesson

1. Ms Stiles: Right. Raise your hand if you know what an orbit is.
2. Michele: It's where something goes around something.
3. Ms Stiles: Good. I looked it up yesterday and it said "The path a planet takes around the Sun." Does the orbit move?
4. Students: No, things move around it.
5. Ms Stiles: Do they go in a straight line?
6. Students: No.
7. Ms Stiles: What do they do?
8. Kris: It goes around the Sun.
9. Student: It could be in an oval.
10. Ms Stiles: It could be an oval or a circle, you are right. You can think about it this way. See those white lines on the poster by the "Z?"
11. Students: Yeah.

12. Ms Stiles: That is an orbit. You can think about it that way. It is kind of like an invisible train track that goes around the Sun and never moves. The planet always goes around the Sun in the same way.

So Ms Stiles had a better understanding of orbits than she did of Newton's Third Law, and was more easily able to translate that vision into something second graders could visualise (Utterance 12). She followed this discussion with a lively enactment of the movements of the Earth, Moon, and Sun as role played by the students. This lesson gave the students a part in which to be active, was a concept more attainable by second graders, and was a concept better understood by the teacher. Of course, "orbits" is a topic much easier to teach than Newton's Law, but the sequence still illustrates that Ms Stiles was triggered to improve her knowledge of the content prior to instruction. Like the experienced teachers in this study, for this lesson she was prompted by her need to teach an idea to read and research the topic prior to instruction.

Implications

One of the constraints to teaching elementary science is incomplete content knowledge (Perkes, 1975; Harlen, 1997; Tobin, Briscoe, & Holman, 1990). Harlen (1997) found that elementary teachers used specific coping strategies that enabled them to teach science whether or not they felt comfortable with their content knowledge. The teachers in this study did not use the same strategies identified by Harlen, who studied reluctant science teachers. The teachers in this study were science enthusiasts who saw a place for science in the elementary curriculum. Thus they taught science every day rather than avoiding it, and sought out ways to have students interact with materials. They designed their own astronomy unit, and focused on discussion of ideas rather than using a prescriptive lesson plan. However, they still recognised that they had weaknesses in their understandings of the astronomy content. The experienced teachers in this study listened to students to find out their views, questions, and misconceptions, about astronomy, and sought to research and read to enhance their knowledge of astronomy so they could improve their students' understandings. By helping elementary teachers become more aware of student misconceptions of content we can help elementary teachers seek to become more knowledgeable about the content themselves because they will seek to address student questions and ideas.

Both experienced teachers, and later the preservice teacher, used non-fiction children's tradebooks to help relate astronomical phenomena to these children. One might easily question whether these teachers were actually gaining knowledge of astronomy beyond simple factual knowledge – it is likely they were not increasing their conceptual knowledge gain. Non-fiction children's tradebooks, while helpful in extending factual knowledge, may indeed also hinder development of some kinds of knowledge. Students, and teachers, may be limited in choice of science topic to study simply because of the lack of availability of tradebooks for some science content areas. Tradebooks for the physical sciences, for example, are particularly rare.

Tradebooks may also contain factual errors, especially if teachers and students read ones that are outdated. Again, simply reading and researching non-fiction sources does not guarantee that the teachers are building sound conceptual understandings of content. However, the need to help their students build an understanding was a trigger for the experienced teachers to access non-fiction material that could assist children's development of conceptual understanding of astronomical phenomena, and they often chose non-fiction children's tradebooks as a resource.

If student ideas and misconceptions do trigger elementary teachers to seek to increase their knowledge of the content, teachers can learn strategies for eliciting student ideas. Both teachers in this study elicited students' ideas as a starting point to every lesson by asking them to share their ideas regarding the content. Strategies that appeared to be useful were initial open-ended and probing question strategies that required students to discuss ideas and negotiate meanings and understandings of content and experiences in their classrooms. Upon knowing student ideas, teachers could then choose to study scientific views and address those student ideas in instruction. A further recommendation from this study is that it is not necessary to elicit all student ideas in the classroom, but to find out which ideas are shared by the most students and use those ideas in planning ways for addressing student ideas. It is important that teachers recognise the influence student ideas have on student learning, and to develop strategies for identifying conceptions that are held by the majority of students, followed by strategies for dealing with those conceptions (Berliner, 1987; Bromme, 1987).

Finally, it must be remembered that not all interns can handle the sophistication of responding to children's ideas. Interns are concerned with many other factors that may not be concerns for experienced teachers (Hollingsworth, 1989). The Concerns Based Adoption Model (CBAM; Loucks-Horsley, 1996) indicates that persons new at a task are first at a level of Personal Concern – or are concerned how they are affected by the process. For instance, Ms Stiles stated that she was concerned that her teaching went well. It is understandable that she felt this concern, particularly because so many others were observing her instruction. She was not yet at a level of concern that enabled her to focus on how her instruction was influencing the learners in her classroom. So student ideas and misconceptions did not influence her to increase her knowledge. In fact, she seemed surprised when they responded in ways that shared misconceptions. It was interesting to note that toward the end of her internship she did, in fact, use non-fiction science tradebooks to enhance her content knowledge prior to teaching a lesson as did the experienced teachers. This supplies some evidence that with experience teachers become better at compensating for incomplete content knowledge.

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