AN ABSTRACT OF THE THESIS OF

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Abstract approved: Signature redacted for privacy.

Norman G. Lederman

A large body of research has examined how children enter the science classroom with previously formed ideas about the content they will learn. These ideas influence how the child interprets instruction. This study reversed the investigative focus by exploring how children's ideas in science influence teaching. Specifically, the study examined how primary teachers identify student ideas, how they react to student ideas, and how teacher responses impact students' learning of science.

Two experienced second grade teachers, and one teacher intern were observed, videotaped, and interviewed over the course of an eight-week astronomy unit. Ten students in each class participated in pre- and post-instruction interviews to determine development of content understanding. All interviews and observations were video- and audio-taped and transcribed for data analysis.

Results indicated that while primary teachers approached science instruction differently, but children's ideas influenced all three teachers. To identify student ideas teachers used idea invitation and probing questions. Teacher One used lesson development, demonstration, explanation, literature connection and scaffolding strategies

to help students change their conceptions. Teacher Two used explanation, literature connection, and activity debrief strategies to address student ideas. The Intern Teacher used strategies such as ignoring, partial acknowledgement, and leading that discouraged the expression of ideas. While students in both classrooms improved in their knowledge, those with Teacher One had more accurate knowledge of astronomy at the conclusion of the study.

Science instruction in these classrooms played a major role in developing general literacy skills. Teachers used whole class and small group discussions, as well as reading and writing assignments to help students learn astronomy content. Several factors, such as time, teacher knowledge, and number of students sharing ideas, mitigated delivery of instruction.

Implications are that children's ideas do play a role in primary teaching by (a) influencing teacher planning of lessons designed to elicit and address ideas, (b) encouraging teachers to seek ways of responding to student ideas, including the cycling of ideas repeatedly in instruction, (c) forming a basis for dialogue and discussion about science, and (d) informing teachers of areas for improving their own content knowledge.

THE INFLUENCE OF PRIMARY CHILDREN'S IDEAS IN SCIENCE ON TEACHING PRACTICE

by

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Once upon a time there lived and worked a first grade teacher in the Kingdom of Finley. She loved her work, especially teaching science to her students. She enjoyed teaching with her friends, Kathryn Locker, Judy Burns, and Elaine Hagen, from whom she learned so much about teaching to primary children. She began to take classes to learn more about teaching to young children. She happened upon a class about teaching science taught by a powerful sorcerer, Dr. Lawrence B. Flick. From ideas she learned in his class, the first grade teacher recognized that her own teaching of science could be better. There was so much, like the students' own ideas about concepts, that she never before considered when teaching. She approached Sorcerer Flick hoping he would consent to have her become an apprentice so she could embark on a Quest for Crystal Clarity to understand more about how children's ideas influence their learning. He had been guiding her in her studies already, and very kindly agreed to continue mentoring her. The first grade teacher excitedly became an apprentice and continued receiving valued input and guidance from Sorcerer Flick.

Sorcerer Flick embarked on a journey to a New Kingdom where there were other Sorcerers of Science Education with whom he wanted to work. A storm in her part of the kingdom prevented the apprentice from traveling at the time, but Sorcerer Flick promised to continue guiding her from afar, which he did, and the apprentice was thankful.

When the storm cleared, the apprentice traveled to the New Kingdom to continue working with Sorcerer Flick. Though Sorcerer Flick was too fresh to the New Kingdom to officially serve as a Major Sorcerer, to the apprentice's delight, he continued to serve

in that role anyway. The apprentice was also very fortunate to receive much guidance from the mighty official Major Sorcerer, Norman G. Lederman. His appreciated direction and guidance helped the apprentice see many new ideas from different viewpoints. Soon the apprentice recognized her good fortune at receiving feedback on her Quest from two such Major Sorcerers. The apprentice continues to appreciate guidance, opportunities, and constructive criticism afforded from both Drs. Flick and Lederman. The apprentice values her good fortune at the opportunity to work with the other powerful Sorcerers who formed a committee to guide her in her Quest—Drs. Michael Mix, Karen Higgins, and Douglas Markle.

While the apprentice was the only first grade teacher in the New Kingdom, she was delighted to meet other apprentices whose work and quests were similar to hers. The apprentice particularly values the enduring friendships with Fouad Abd El Khalick, and now-sorcerer Dr. Janet M. Scholz, both of whom she has spent many enjoyable hours discussing ideas and work, and who have provided support and encouragement. The apprentice was also very fortunate to be welcomed into the classrooms of two wonderful primary teachers from the New Kingdom, Holly Harris and Sharon Jones

It is quite obvious to the apprentice, now Sorcerer (!), that the Quest has just begun, and that no such Quest is ever a journey taken alone. The apprentice is fortunate to have had so much valuable guidance from so many wonderful people. She especially appreciates her collegial friendship with Major Sorcerer Flick, without whom she would never have taken the first step.

And the Quest continues…

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Dedicated with love to my father,

Larry Earl Dickinson

For many years of support, both financial and emotional

with love to my mother,

Joan Elma Dickinson

For all the letters and family photographs

And my brothers,

Michael Earl and Mark Dean

For always being there

THE INFLUENCE OF PRIMARY CHILDREN'S IDEAS IN SCIENCE ON TEACHING PRACTICE

Chapter I

The Problem

Introduction

Current reforms in science education focus on the need for students to conceptually understand science rather than simply knowing a breadth of science facts (AAAS, 1993; NRC, 1996). These recommendations are for students of all grade levels, from kindergarten through high school and beyond. Understanding science necessitates conceptualizing content. To understand science conceptually means knowledge of ideas of science and the relationships between these ideas. This understanding includes knowledge of ways to use the ideas to explain and predict other natural phenomena, and ways to apply them to other events (NRC, 1996). Developing understanding presupposes that students are actively engaged with the ideas of science. The reforms further suggest that scientific understanding can be gained through inquiry instruction generated from student experiences.

According to Kelly's (1955) theory of personal constructs, thought processes are psychologically developed by experiences that serve to help the person anticipate future events. Prior experiences form background knowledge that people use to inform inferences made from future experiences. Thus, in any science classroom, it can be expected that children will have had experiences that helped them develop stable and functional constructs about the world. These constructs, or ideas, will influence interpretations made of explorations in science. Children's ideas are defined as experience-based explanations constructed by the learner to make a range of phenomena and objects intelligible (Wandersee, Mintzes, & Novak, 1994). Children's ideas are stable and resistant to change (Carey, 1985; Driver, Guesne, & Tiberghien; Novak, 1988; Stepans, Beiswinger, & Dyche, 1986). As long as the idea serves the learner in making sense of the world, it will remain the learner's theory (Driver, et al, 1985; Osborne & Freyburg, 1985). Children's ideas develop early, and by the age of five or six children have evolved to a robust and serviceable set of theories about their world (Carey 1985; Gardner, 1991; Piaget, 1929). Regardless of the recognized influence of student ideas, the reforms have recommended conceptual understanding of science.

Young children's ideas have been studied for many decades, with Piaget (1929) pioneering their study with the development and use of the clinical interview method. Science educators have adapted the clinical interview method to explore children's ideas in a plethora of science content areas (Osborne & Freyburg, 1985; Posner & Gertzog, 1982; Thier, 1965). Results of the study of children's ideas show that school children can proceed through their school careers and retain misconceptions about many science concepts (Anderson & Smith, 1986; Bar, 1989; Bishop & Anderson, 1990; Griminelli Tomasini, Gandolfi, & Pecordi Balandi, 1990; Hashweh, 1988; Hesse & Anderson, 1992; Nussbaum & Novak, 1976). The kinds of science instruction children are receiving do not seem to be effective in helping students change their conceptions toward the scientific convention. Students may be presented with evidence that their ideas are incongruent with an experiment or problem and reject the evidence, or reinterpret it differently within their own beliefs (Osborne & Freyburg, 1985). Even when students present what appear to be correct responses, they continue to harbor their own ideas (Driver, et al, 1985; Erlwanger, 1975; Herscovics, 1989; Osborne & Freyburg, 1985).

What is necessary to help children's ideas develop toward the scientific convention and the visions of the reforms that recommend teaching for understanding? Posner, Strike, Hewson, and Gertzog (1982) theorize that students remain committed to their ideas unless they are shown the necessity of modification. The child must be dissatisfied with the existing conception, meaning the child's idea must no longer make sense to the child in explaining the concept. A new idea must be intelligible as well as plausible. Finally, the conception must be fruitful and make sense in many situations. Strike and Posner (1992) reiterated that their theory of conceptual change is not a prescription for instruction, but only conditions necessary for ideas to change. A way for teachers to help students change ideas would be to scaffold them to a more accurate level of understanding (Rogoff, 1990; Vygotsky, 1991). Scaffolding children's thinking in curricular areas is a strength of primary teachers (Cazden, 1988). Primary children are not inhibited from sharing ideas, nor are they willing to keep them quiet. They are active, and willing to describe what they are doing and thinking. Primary teachers who are attentive to these students are fortunate with being able to elicit ideas with little prompting. Primary teachers are also fortunate in the students' willingness to manipulate equipment and discuss what they are learning. Furthermore, teacher input in the discussion helps to scaffold students to new understandings (Gallas, 1995).

Though elementary teachers have strengths that contribute to providing good science instruction, there are at least four barriers to providing effective science instruction. These barriers include (1) teacher content knowledge, (2) available time for science instruction, (3) teacher confidence for science teaching, and (4) teacher experience with hands-on science.

Some may question whether an elementary teacher not fully versed in the science content being taught is capable of teaching science conceptually, or even in recognizing children's ideas. Most elementary teachers are not science specialists. Elementary-aged children do not recognize the difference between scientific ideas and general ideas about the world. To these young students, they are simply learning about the world; there is no compartmentalization between science and general ideas. Science is only one of numerous subjects in which an elementary teacher must provide instruction. Arguably, the most important task for an elementary teacher is to teach students to be literate readers and writers in the context of an integrated, or at least conceptually wholistic curriculum. Elementary teachers necessarily have an expertise in language arts, and can use this expertise to help scaffold student learning in science.

Science, as a separate subject, in the primary grades is given a smaller amount of instructional time in comparison to other subjects. Fitch and Fisher (1979) reported about 88-135 minutes per week spent on science in the primary grades; they did not discuss how that time allotment compared with other curricular areas. Cawelti and Adkisson (1985) found that in a typical fourth grade classroom about 140 minutes were spent on science per week, in contrast with 501 minutes spent on reading, and 259 minutes spent in math. In a more recent report, Stefanich (1992) stated that in 50% of the primary classrooms activity-based science comprised a maximum of 20% of the instructional time. In the remainder of the primary classrooms all of the instructional time for science was composed of textbook readings. Science does not comprise a large portion of classroom time in elementary schools, and when science is taught in the primary grades it is often through use of textbooks. Moreover, having primary children follow along in a textbook as a passage is read is not considered teaching science conceptually.

In addition to limited time spent on science, other factors influence teaching elementary science: (a) teacher perception of the importance of science in an elementary curriculum, (b) limited content knowledge held by elementary teachers, and (c) limited experience through formal coursework in participating in and presenting hands-on science. Elementary teachers do not often see science as a pertinent topic, but rather as something to be taught only when other subjects have been covered (Abell & Roth, 1992; Schoeneberger & Russell, 1986; Tilgner, 1990; Tobin, Briscoe & Holman, 1990). Administrators do not always see science as an important subject in elementary schools (Schoeneberger & Russell, 1986; Tilgner 1990). This perception of science as of little importance leads to less funding and support of elementary science (Stefanich, 1992). Because of lower funding, elementary teachers are likely to have inadequate equipment for teaching science. Inadequate equipment and limited time often inhibit teachers from providing in-depth instruction (Stefanich, 1992; Tilgner, 1990).

Elementary teachers lack confidence in their abilities to teach science because of weak content knowledge (Borko, 1993; Enochs & Riggs, 1990; Smith & Neale, 1989). Even elementary science enthusiasts, who effectively teach concepts for which they have good background knowledge, have difficulty teaching other science concepts because of inadequate content knowledge (Abell & Roth, 1992). Lack of confidence and content knowledge is not unique to science, but in other curricular areas, such as social studies, as well.

Elementary teachers often have not had experience participating in hands-on science, and therefore are unsure of how it should proceed in their own classrooms (Bybee, 1993). Typically, elementary teachers take introductory science courses in their teacher preparation programs, yet those courses often do not suit their needs or interests (Tobias, 1992). Elementary teachers with a positive attitude and interest in learning science may find college science coursework inhibiting to their learning (Dickinson & Flick, 1996). Even with these barriers to teaching science, many elementary teachers provide effective instruction. Research evidence suggests this effective instruction is accomplished by the elementary teachers using other areas of strength to help them provide instruction that allows students to share ideas and conceptualize what they are learning in science (Flick, 1995).

Despite these constraints, elementary teachers are expected to teach science for conceptual understanding (AAAS, 1993; NRC, 1996). An additional challenge for primary teachers is to teach science conceptually given the developmental levels of their students. Primary-aged students generally do not see the same logical connections conceived by adults (Carey, 1985a, 1985b; Piaget, 1957). College science courses taken by primary teachers are not appropriate or useful in helping them understand how to help children see logical and scientific connections. Scientific understandings may not always be attainable by children of primary age. For example, the National Science Education Standards (1996) recommend that students be able to distinguish the difference between what is and is not a scientific idea. It is questionable whether primary students are capable of differentiating between scientific and non-scientific ideas. However, the same students do have the ability for conceptual thinking in the form of generalized explanations for events based on experience (Nelson, 1986). This developing conceptual ability can be tapped during instruction to generate discussion of scientific concepts.

Given the barriers to elementary science teaching, the question remains: What knowledge about science and science teaching supports teachers in meeting the science standards at the primary grade level?

Statement of the Problem

Given the recommendations of national reforms for students to develop a conceptual understanding of science, a logical starting point is to study teachers' conceptions of science. Evidence exists for what elementary teachers know about science content (Kruger, Palacio, & Summers, 1992; Kruger, & Summers, 1989; Lawrenz, 1986; Smith, & Neale, 1989, Stoddart, Connell, Stofflett, & Peck, 1993). Too often the problem is cast in terms of teacher deficiencies which has led to a one-sided recommendation to improve teacher knowledge without better understanding of the relationship among science, the elementary curriculum, and developmental level of students (Flick, 1995, 1996). In order to begin to help students meet the standards, a bigger problem must be studied: how do teachers attempt to help students develop conceptual understanding of science? Knowledge of student conceptions has been productive in helping students develop more accurate understandings of science. The current study focused on how primary teachers acted on student ideas, as keys to teaching toward conceptual understanding. The ideas students bring to the science classroom have an impact on what students gain from instruction as they are generating meanings from their experiences and discussions. Children's ideas interact with those presented by the teacher. Even evidence contradictory to chidrlen's understandings can be interpreted by them to support their own naive ideas (Osborne & Wittrock, 1983). In the absence of a teacher who understands and uses knowledge of children's ideas to inform instruction, children are unlikely to develop their ideas toward the scientific convention (Driver, Guesne, & Tiberghien, 1985).

The following scenario from a first grade classroom illustrates the importance of teacher knowledge, children's ideas, and the impact of children's ideas on classroom practice. The teacher is not a science specialist. However, she does understand the content being taught. She also appreciates its value and relationship to the elementary curriculum. She is enthusiastic and confident in teaching it. Abell and Roth (1992) found that a science enthusiast elementary teacher was able to provide effective science instruction of science content of which she had accurate scientific understanding. In the same classroom the teacher was not able to effectively teach a topic of which she had little understanding. Thus, it is necessary for an elementary teacher to have content knowledge that is scientifically accurate, yet having content knowledge is not sufficient for effective teaching of science. The teacher in the following scenario has an accurate conception of Archimedes' Principle. She understands that the upthrust on an object is equal to the weight of the water it displaces. Having this knowledge, however, is not sufficient in enabling her in providing instruction for developing understanding.

> <u>Teacher:</u> Today we are going to begin studying floating and sinking. We are going to test some things to see what happens to water when you place different things inside the tubs. I would like you to pay close attention to the shape of the items you are testing, and to what the water does when you place things in the tub. (The teacher is trying to provide background and purpose for the upcoming exploration.)

(Students spent some time testing items for buoyancy in tubs of water, and then reconvened for a class discussion. They worked in groups of four, placing one item at a time in a tub. There was lots of splashing and spilling of water.)

Teacher: So what did you find out from our experiments?

Crystal: Light things float and heavy things sink. (Most items chosen for testing fit this pattern.)

Michael: Round things sink and square things float. (Most items chosen for testing fit this pattern.)

Teacher: What did you notice about the water being pushed aside when you put the different items in the tub? What happened when you dropped the sinker in the tub? (It appears the teacher was not aware of the ideas the children were expressing. Her comments did not respond to their statements.)

Melvin: It splashed water all over the desk! And then it sunk.

Though the teacher in the scenario was not a science specialist, she understood the concept of water displacement, and was trying to help her students focus on how water was displaced depending on the depth an item rests in the water. If the item sunk completely, it would displace more water than if it remained floating in the water. She was providing her students with opportunities to explore Archimedes' Principle while actively engaging in experimentation. She was an experienced primary teacher, and realized that children enjoy being actively involved and learn best in this fashion. Activities she provided were developmentally appropriate. However, she was unaware of the ideas her students already held, or had chosen not to act on their ideas about the role water plays in buoyancy. Her students did not confront their own conceptions.

The teacher's goal was to help students begin building an understanding of the principle of buoyancy by noticing the change in water level in the tub as items were placed inside. Through hindsight it is possible to note problems with instruction that could have influenced the lack of student understanding of this concept. There are three feasible problems with the instruction as presented.

First, it is possible that when the teacher did not pick up on the ideas expressed by the students, she was unable to guide them in critically important ways to help them develop bigger ideas about buoyancy. She was teaching two related ideas affecting buoyancy, shape and water displacement, which are developmentally inappropriate for children of this age given it was their first experience with the scientific idea of buoyancy. Michael made a logical inference about the items he tested when he stated that circles sink and squares float. He did not observe water displacement. Had the teacher recognized or responded to his idea, she may have asked him to share his evidence for his ideas, and provided more activities for Michael to show him that not all circles sink nor do all squares float. She may have provided activities to show him that the shape of an item does affect its buoyancy, but in more subtle ways than what he believed. It was later discovered that Crystal strongly believed heavy things would sink and light things would float. This belief was so strong that she maintained a boat on the river would sink were it not intermittently pushed back up by rocks it would hit beneath the surface of the water. Had the teacher recognized this idea, she may have responded by having Crystal test items of different shapes that were the same weight, some that floated and some that would sink, or had Crystal explore items of different weights, some heavy that would float, and some light that would sink.

Second, it is possible that the activities set up for the students to observe were inappropriate for the children. For instance, in the activity provided, the change in water level was too subtle to notice, particularly when the water was splashing from the tubs as items were placed inside. The teacher had asked students to note what happened with the water when items were placed inside, hoping they would note the rising level, yet Melvin noted the water splashed when items were added. His observation was certainly true, yet was not the observation the teacher expected the students would make. The teacher provided activities she believed would help students understand water displacement. However, what students noticed and focused upon were dictated by their own view of the activity. Their trials necessarily caused spillage of water, eliminating any chance of noticing differences in the level of the water, even if the children had been focused on watching it. The activity provided here seemed appropriate for primary students, but the goal of instruction for students to notice changing water levels was likely too elusive, particularly from a single exploration. A possible alternative to help students notice the change in water level would have been to have students mark the water level in their tubs, and carefully place items in the tubs without splashing, and then note the rising level by making a new mark. These alterations might have been suggested by clear attention to student remarks.

A third possibility to the outcome of the lesson is that the teacher was not knowledgeable enough to provide directions encouraging students to confront their ideas about buoyancy. However, though the teacher understood Archimedes' Principle, she was still unsuccessful in providing experiences to help students develop appropriate understandings. This teacher had taken college level physics, but the course did not include hands-on lab experiences. Even though the teacher knew the science concept, this knowledge was not sufficient in helping her provide appropriate instruction to help children understand and confront their ideas. Responding to student ideas as noted above required knowledge beyond what students learned as well as knowledge consistent with the views of science. Other kinds of knowledge would be important for the teacher to have, such as knowledge of pedagogy and the developmental characteristics of the students.

Another kind of knowledge that would be important for the teacher was pedagogical content knowledge. Pedagogical content knowledge refers to the ways teachers transform content knowledge to a form students can interpret (Shulman, 1986, 1987). A key aspect of pedagogical content knowledge is a teacher's knowledge of the ideas children already have about the subject. Pedagogical content knowledge allows teachers to choose representations, examples, experiences, or hold discussions to help students deepen their understandings. While pedagogical content knowledge appears to focus on facility with teaching strategies, it is dependent on the content itself. Pedagogical content knowledge links content to be delivered with knowledge of ideas children bring with them to the science classroom to support the teacher's decision for how to represent science content for instruction (Geddis, Onslow, Beynon, & Oeschk, 1993). Knowing students' ideas is part of the pedagogical content knowledge of elementary teaching, and allows the teacher to provide experiences to help students understand the content.

Students in first grade have had numerous experiences being in, and playing with, water. Through these experiences children have developed useable ideas about floating and sinking. In an interview of 113 children from one elementary school, of ages five to seven, Butts, Hofman, and Anderson (1993) found those ideas include (a) things that sink are hard and metal, (b) things that sink are all the same color, (c) things that sink are small, and things that float are big, and (d) things float or sink because they want to. Of course, there are no guarantees that the children in the sample classroom have the same ideas of the children interviewed in the study. However the interview responses obtained by Butts, et al. (1993) show the connection between children's ideas and official science knowledge. Teachers need to understand that students do come to the classroom with already formed ideas.

Because children's ideas exert such an influence on the effectiveness of classroom instruction, there have been recommendations to help students move toward a more accurate viewpoint (Gilbert, Osborne, & Fensham, 1982). Students need to be made aware of the existence of the official science viewpoint, as well as their own views. Students need to be shown the official scientific view and to develop their ideas toward that view. To help students see the usefulness of an official scientific viewpoint, teachers need to be aware of children's ideas and elicit their own students' views to plan activities and discussions to help narrow the gap between children's ideas and the official scientific viewpoint. Indeed, how could a teacher possibly help students be aware of their views, if the teacher is not aware of those ideas? In the absence of knowing students' views, teachers can be teaching directly past students without even realizing it (Erlwanger, 1975). The student may be able to provide the expected response, yet maintain an understanding inconsistent from that of the teacher or the scientist. If the teacher is aware of the views children bring with them to science classrooms, the teacher may adjust instruction to take these ideas into account.

This study examined how children's ideas influenced instruction in two primary classrooms. If the teacher had an awareness of the importance of children's idea and the specific conceptions her own students hold about a science concept, would she choose to teach differently? How would the teacher elicit and recognize student ideas and plan activities for students to confront those ideas; and how would this affect student learning? There are many other competing factors in a classroom that influence teacher actions, such as classroom management concerns, being secure with colleagues and parents, and keeping one's wits in critical moments, (Calderhead, 1987; Huberman, 1985). How would the teacher use student ideas in implementing instruction in the midst of the many other competing factors in classrooms? In addition, teachers who hold a strong belief about how a subject should be taught tend to teach in ways that reflect that belief (Clark & Yinger, 1987). Therefore, it would seem that teachers would be influenced in their teaching if they believed in the impact of children's ideas on science learning. How would the instruction in the scenario have proceeded differently if the teacher had acted on her students' ideas?

Previous research on children's ideas has focused on describing them, providing knowledge of many misconceptions that are likely to be found in students of different ages in different subject areas (Bar, 1989; Hashweh, 1988; Nussbaum & Novak, 1976; Piaget, 1929). In addition, methods based on student conceptions, such as the learning cycle (Smith,1983), analogy (Stavy, 1991), or written and oral language (Fellows, 1994), have been used by researchers to help teachers change these misconceptions in their students. However, it was not clear in the studies whether the classroom teachers were aware of their own students' ideas or even if they were aware of typical misconceptions held by students in their grades. Students in such classrooms continued to retain their erroneous ideas, and the teacher was unlikely to realize their students held such ideas.

Additionally, classroom observations were not always conducted, or were sporadically conducted, that limited information about how teachers actually implemented the procedures. Some methods that researchers used for identifying student ideas, such as clinical interviews, are not feasible for teachers to use in every day practice.

This study recognized the strengths of prior research in describing misconceptions, and in investigating methods to change student ideas. The study built upon previous research and focused on what classroom teachers do with children's ideas and how knowledge of those ideas impacted teaching practice. Perhaps instruction has been ineffective in changing children's ideas because, though there have been many studies delineating the kinds of ideas children hold, there has been little impact of these ideas on classroom practice (Hewson, Bell, Griminelli Tomasini, Pecordi Balandi, Hennessey, & Zeitsman, 1995). Prior research on changing children's ideas has not included teacher knowledge of student misconceptions. The impact of children's ideas on classroom practice needs to be studied to see whether knowledge of students' ideas can influence teacher practice. Teachers with knowledge of student ideas may be influenced to develop instructional activities that help students' ideas move toward scientific conceptions.

The purpose of this study was to explore how children's science impacts science instruction in the primary grades. Specifically, the study investigated:

1. How do primary teachers recognize and interpret student ideas?
2. In what ways do primary teachers plan for and react to students' ideas?
3. In what ways do students' conceptions change over the course of a unit that addressed their specific ideas?

Significance of the Study

The study provides information about primary science teaching, children's ideas, and their impact on classroom practice. Understanding the impact of children's ideas on classroom practice is important for teacher education programs. Describing how experienced teachers use student understandings to help inform instruction provides examples for use in science methods courses. If knowledge of and acting on children's ideas improves science teaching in the primary grades, children's ideas deserve a greater emphasis in teacher education programs. Perhaps teacher education must provide more instruction in identifying student ideas, rather than instruction only of typical misconceptions that children are likely to hold about various science topics. However, if awareness of children's ideas has no impact on teacher practice, and it is not important for teachers to know the ideas of the students in their classrooms, then this avenue of research should not be further pursued.

The study provides information in the type of knowledge necessary for teachers to effectively teach primary science. It gives background of current practice in primary classrooms, and informs how teachers' content knowledge, pedagogy, awareness of students' ideas, and knowledge of students, interact and influence the teaching of science in the primary grades.

The study provides knowledge about the kinds of science learning taking place in primary classrooms. Teacher knowledge of student ideas can influence teaching, and thus, can influence what students gain from such instruction. The kinds of knowledge students can gain from teachers acting on their ideas is illuminated in this study.

If teachers do not recognize their students' ideas, future research should focus on effective ways to help teachers identify students' ideas. If teachers do recognize student ideas, but are unable to address them in classroom practice, research should identify reasons for not addressing students' ideas. It would be necessary to focus on ways to help elementary teachers develop their own abilities to address students' ideas via activities and discussions.

If the results indicate that teachers recognize and address students' ideas an important component of pedagogical content knowledge will be found. Evidence will confirm that teacher preparation courses should be specifically designed to focus on the development of pedagogical content knowledge.

Chapter II

Review of the Literature

Introduction

The purpose of this study was to describe how experienced primary teachers recognize student ideas, how they respond to the ideas, and the effect of their actions on their students. To design an appropriate study to explore these areas it was necessary to have a thorough background in three areas. First, it was necessary to note the background research in children's ideas, as well as in changing the ideas; thus one section reviews the research on children's science conceptions. Included in this section are studies investigating strategies to help change those ideas toward the scientific convention. The areas of research included within this section are conceptual change studies and use of the learning cycle. Conceptual change strategies focus on using methods such as confronting students with discrepant events, or use of analogy, to help students change their ideas. The learning cycle has been used as a conceptual change method in science classrooms and is a strategy originally developed for use in elementary classrooms.

Because the study makes inferences about the teacher's thinking a focus is also included in how the teacher uses knowledge of student ideas to inform teaching. A second area for literature review was that of teacher's thinking and teacher knowledge. Within this section are (1) studies comprising teacher thought processes and decision-making and (2) elementary teacher science content knowledge and pedagogical content knowledge.

Third, this study examined how teachers interpret the ideas of primary students. There is therefore a need to examine the kinds of ideas children of this age form about the natural world and how their ideas are expressed. A section discussing the psychology of young children is included. Studies are reported that describe thought processes, cognitive development, and abilities of young children, from about four to eight years of age which comprises the primary grades.

Children's Science and Strategies for Changing Ideas

The literature in this section begins with a review of studies describing a selection of primary children's ideas in science. It has been established in the science education community that children bring their own ideas with them to the classroom about many science concepts (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). These ideas, while serviceable to the learner, are not consistent with scientific conventions. Studies have been selected that use a variety of methods to obtain ideas and conceptions of children of elementary age, with an emphasis of those in the primary grades. The studies point out the importance of acknowledging the existence of children's ideas when planning for and teaching primary science.

The next portion reviews studies that have purported to be successful in changing children's ideas. The strategies used in the studies are subsumed under the term conceptual change strategies. Guzzetti, Snyder, Glass, and Gamas (1993) conducted a meta-analysis comparing conceptual change strategies reported in science and reading education literature. One of the greatest difficulties they reported in their search was the inconsistent definition for a conceptual change strategy. For purposes of this review, conceptual change strategies are defined as those through which teachers were attempting to change student ideas from alternative conceptions to scientific convention, using one or more aspects of conceptual change teaching methods. These methods include use of analogy, confrontation of student ideas to cause students to rethink their ideas, and having students interact with materials and discuss the meanings they are making from their interactions.

The third area reviewed in this section includes studies on the use and understanding of the learning cycle by teachers. The learning cycle was developed for use in elementary grades to help teachers provide instruction taking into account student ideas and to help students experience science in a manner similar to that of a scientist. Karplus and Thier (1967) are generally credited with developing the learning cycle model of science instruction. However, in their book, *A New Look at Elementary Science,* there is no mention of the "learning cycle" per se, but a method is given for teaching elementary science that helps build on student thinking and keeps students actively involved in learning science. There is a recommendation for children of all ages to experience science as closely to how a scientist experiences it as possible. Karplus and Thier discuss the importance of children's preconceptions in helping them make inferences about their explorations. It is the preconceptions that determine the generalization a child can infer from experiences. To build a scientific conception the child must build beyond his or her prior ideas, assuming their ideas are not already scientific.

Karplus and Thier describe the lessons of their teaching recommendations that must have been later termed the "learning cycle (p. 40)." They did not describe this strategy as a cycle of phases, but as different lesson types that were necessary for students to develop conceptual understanding. The first lesson type comprised preliminary exploration during which students actively manipulated materials. The second lesson type, in which a new concept was introduced, termed "invention," included more of a direct instruction feel with the teacher giving the students information. The third lesson type was discovery, which is the recognition of a relationship between two ideas or between two observations, or an idea and an observation. According to the authors, the discovery lessons should occupy the most teaching time, but the other two types are essential to the learning that led to the discovery.

Lawson, Abraham, and Renner (1989), elaborating on Karplus and Thier's (1967) work, described three different learning cycles that represent three points along a continuum from descriptive to experimental science. The three types are descriptive, empirical-abductive, and hypothetical-deductive. The difference among the three is the degree to which students gather data in a descriptive fashion or set out to test alternative hypotheses. In the descriptive learning cycle only descriptive patterns such as seriation and classification are required. In the hypothetical-deductive cycle students need the ability to control variables and correlate their reasoning with patterns they have seen. The empirical-abductive learning cycle requires descriptive reasoning patterns as well as some higher order patterns. It is likely that teachers of primary students focus on activities using the descriptive learning cycle.

Children's Ideas

Bar (1989) conducted a study to define children's ideas of the water cycle. The ages of the children ranged from 5 to 15 years old. The goal of the study was to try to order the development of a concept of the water cycle through stages. Three hundred children were included in the investigation. The study included approximately equal numbers of girls and boys.

The study was conducted using the clinical interview method. Children were individually asked for their views on evaporation, about the clouds, and about rainfall. It was found that though all children state that water evaporated, they had different definitions for exactly what that meant. It was found that children of ages five and six believed that during evaporation, water simply disappeared. Children of ages seven and eight tended to believe that the water penetrated into the floor and went away. At about ages nine and ten children believed that water evaporated into a container, such as the clouds. From about ages eight to eleven, children began to understand that water scattered into the air when it evaporates.

To explain rainfall, younger children tended to answer that clouds collided, causing the rain to be released, but older children tended to think rain fell when the clouds became heavy. Some participants were shown to believe that rain fell when droplets within the clouds grew heavy, and others believed the whole clouds fell when it rained.

Concerning the water cycle, children of ages five to seven did not believe water was conserved. Rather, they tended to answer in ways indicating they believed in divine intervention causing reservoirs in the sky to be opened. Other children tended to believe that clouds opened and rain fell.

Children of ages six to eight tended to believe that water was conserved, but that air was not. They believed the clouds went into the sea and collected water and went to other places to give rain. This view peaked at first grade. Children of age nine also said that clouds were made of water vapor created when the sea was heated by the sun to a high temperature or from water vapor coming from boiling kettles.

By age nine and ten, children began to see that water and air were conserved in the water cycle, and that water changed into vapor. Children in this age group stated that clouds were made from water that evaporated from puddles. The rain fell when the clouds become cold or heavy. Sea water evaporates to make clouds, but it is not the only source of water that evaporates to make clouds.

By age 11 to 15 it was found that children believed water and air was conserved. Children stated that air, vapor, and water contributed to the weight of clouds.

Bar stated that the development of ideas can be described as a movement from concrete to abstract form. The ideas developed beginning with the thought that a mass of water always remained at a liquid phase, to an idea that water changed into a gas, or small droplets and then evaporated to be contained in clouds, to a form where water became vapor, and went into the air. At the final idea, no specific container, such as a cloud, was needed.

Thier (1965) conducted a study that used clinical interview techniques to gather first graders' understandings of matter. The study was conducted to provide an evaluation of a science unit's success on the learning of first graders and to see whether interviewing was a good method to use for gathering ideas of young children.

Thirty test group first grade children studied a special unit called *Material Objects.* The 30 control group children did not study the unit. The test group children were selected for interview by choosing every other child on the alphabetical class list until 30 had been selected. The same method was used to select the control group children for interview from a different school within the same district. All children were taught by regular classroom teachers.

Both test and control children were asked the same questions, and the interview was audio-taped. The children were interviewed individually. Props, such as crackers and salt, were used to help prompt students to share their ideas. Test group children received instruction from the *Material Objects* curriculum.

During the interviews children were asked to describe different objects, such as a soda cracker, white crystals, water, and white powder. Children in the test group mentioned a total of 304 properties, with a range of 6 to 16 properties per child. In the control group children mentioned a total of 179 properties, with a range of from 1 to 12 properties per child. The researcher ran a *t*-test and found a significant difference beyond the .001 level between the two groups.

Children were also asked to describe similarities and differences between material objects. Test group children reported a total of 85 similarities and differences with a range of 1 to 5, and a mean of 2.8 similarities and differences per child. Control group children reported a total of 62 similarities and differences with a mean of 2.1 similarities and differences per child. A *t*-test found a significant difference between means at the .05 level.

In other instances there was a significant increase in the number of explanations the test group could make about matter over the control group. The difference between the test and control group responses indicated that, in the absence of appropriate instruction, children were unable to change their ideas toward the scientific convention.

In one instance control group and test group children responded similarly to the question asking them to devise an experiment to prove with what a balloon was filled. Neither group satisfactorily designed an experiment to answer this question. The researcher concluded the problem was likely too developmentally difficult for first grade children to solve. The researcher also concluded the unit was successful at teaching children about material properties, and that interviewing was an effective method to use for eliciting ideas of young children.

Nussbaum and Novak (1976) conducted a study assessing second graders' understandings of the earth. They selected second grade children from two classes in one elementary school. Children in the classes were randomly divided into two groups, with the first group being interviewed prior to instruction, and the second group receiving interviews after the sixteenth lesson. The interviews were patterned after Piaget's clinical interview techniques and were designed to draw out the child's version of explanations in assessing concept learning.

The interview process was developed by using 60 second-graders with which to repeat construct formation and construct validation phases. The basic tasks common to nearly all assessments involved predicting directions of imaginary free fall occurring at different points on a model of the earth and explaining these predictions. In the process of developing the interview props were added to help students in their ability to make viable explanations.

Several questions were included in the interview. Children were asked to explain which way a rock fell if a child standing on the earth dropped it. A second question asked children to explain what happened to water in open jars if they were on the bottom of the earth. Another question asked children to explain what happened to the shirt of a child hanging upside down on a swing at the bottom of the earth. A final question was for children to explain what happened to a ball if there were holes drilled through the earth and the ball were dropped in the hole(s). Students were interviewed individually in a room separate from other distractions.

Five different notions, or concepts, were found in the sample group. The interviewer inferred the notions from children's responses to interview items. The researchers were careful to note that these ideas were not likely the only notions held by all children, just those in this sample group.

Notion One: Children who hold notion one concepts believe that the earth is flat. They do not believe it is round like a ball, but that the roundness is caused by something else, such as the road's curves. Some students believe they are inside the round ball of the earth, and are on a flat plane inside the ball.

Notion Two: Children who hold this notion believe the earth is round like a ball, but do not have a notion of unlimited space. The direction of down is always toward the bottom of the paper. The interpretation of this notion is that children do not really believe the earth is round like a ball. They believe there is a definite down, and the down may be below the round ball of the earth, and that they actually live on a plane below the earth.

Notion Three: Children holding notion three have some idea of unlimited space around the earth. However, they do not use the earth as a reference point for up-down directions. When making drawings they draw objects falling off and away from the earth. However, sky is drawn all around the earth.

Notion Four: Children who hold notion four demonstrate some understanding of all elements of the earth concept. They believe the planet is spherical, and understand there is space all around the earth. Up-down directions are away from and toward the earth. Some even explain objects falling toward the earth as a result of gravity. However, they do not refer as Earth's center as the point that determines the down direction.

Notion Five: Children who hold notion five possess all three necessary components of the concept. They demonstrate an understanding of earth as a spherical planet surrounded by space with objects falling to its center.

There were no significant differences between numbers of students holding the different notions before or after instruction. There was some tendency for more students to hold notion four and five after instruction.

It was obvious that students do come to their classrooms with already formed ideas about the earth. The researchers recommended that teachers have some awareness of children's ideas to help guide instruction. In addition, the researchers also noted that some children of second grade age hold abstract conceptions of the earth that are inconsistent with Piaget's theory that children of that age cannot hold ideas of that level. The audio-tutorial lessons that were used in this study did not result in advancements in children's conceptions of the earth.

Dickinson (1987) reported a study in which he explored the development of the concept of material kind in young children. He theorized that the object-level classification system made more sense to young children than the material-level classification system. Children who classified items more by objects than material were unable to tell what an item was made of, and were more likely to call it by its name.

However, with increasing age, children were more likely to refer to the material the object was made of. Children had stronger beliefs that materials retained their identity even though the material's appearance may have changed.

The researcher used subjects from four grade levels, 10 subjects of preschool age (*X*= 4.8), 11 first graders (*X*=6.9), 11 fourth graders (*X*=9.8), and 10 seventh graders (*X*=12.10). The same subjects participated in a series of tasks. There were a total of 26 boys and 16 girls participating in the study. The children were interviewed individually by one experimenter while a second experimenter recorded all responses.

Children were given several tasks to complete during the interview. The first was a sorting task. They were given a set of materials that included chunks of three materials: plastic, wood, and metal with two different colored examples of each. For each item children were asked "What is this?" They were then told what it was in a phrase that included the name of the material in addition to the name of the object, and the color, such as "This is a shiny metal spoon." They were then asked to "Put things together that are made of the same kind of stuff." When children were done sorting they were asked to explain why they put certain things together, and how they knew they were made of the "same stuff."

Following the sorting task, the students were given a set of forced-choice questions. They were shown three items and asked to put the two together that were made of the same kind of stuff. They were then asked to justify why they put the items together, and if there would be another way to group the items to show they were made of the same material.

Next was a transformation task. Children were asked to tell what an object was made of, and then told a story about how the item got chopped up into chunks. They were then told a story about how the item was ground into a powder. They were shown both the chunks and powder forms of the item, and asked of what material each was made. Children who missed the questions were re-asked to ensure they understood the question.

Children then participated in an interview, in which they were asked to tell what different objects were "made of." Care was taken to assure that children did not misunderstand the intent of the question and respond by telling what the item was, rather than of what the item was made.

Results of the sorting task showed that children generally do distinguish between identities of objects and materials of objects. All materials were correctly named by 60% or more of the children at each age. Four-year-olds usually restricted material names to chunks and did not carry this understanding over to powders. Only 30% of the youngest children mentioned material names when labeling spoons, in contrast to 73% or more of older children.

Correct sorting responses included sorting items into three groups (metal, wood, and plastic). Correct responses increased from 0% among four-year-olds to 80% of the seventh graders.

Incorrect response types were of three general types: overuse of color, use of functional object identities, and separation of powders from bulk solids. Sorting results indicated that the youngest children were unclear about material identities and often focused on color and object identities instead. Older children were not categorical in believing that transforming bulk solids to powders does not alter their kind.

Results of the forced choices task were that correct initial choices on both items were made by 60% of the four-year-olds and all the older children. After the challenge questions only 50% of the four-year-olds ended up with correct responses on both, compared with 82% of the first-graders and 91% of the fourth-graders, and all of the seventh graders. Correct initial responses on the two items including powders were given by 10% of the four-year-olds and 73% or more of the older children.

On the forced choice task there were three general patterns: four-year-olds have problems focusing on the material kind of objects, elementary school children can see objects and chunk as being of the same kind but tended to exclude powders, and some fourth graders and all seventh graders were clear about the identity relationship between bulk solids and powders.

During the transformation interviews children were considered to demonstrated the objects' identities had changed but the materials' identities had not if they said (1) the pieces were no longer a(n) airplane/knife, (2) the pieces were still wood/plastic, (3) the pieces were still made of the same kind of stuff, and (4) they did not give verbal explanations that indicated they were thinking of materials as objects. Patterns of successful responding on the wooden airplane appeared among 70% of the four-year-olds and all the older children, and on the plastic knife success patterns appeared among 40% of the four-year-olds and 91% of the older children.

Responses on the powdered materials indicated the rate of correct responses on all three materials rose from 0% of the four-year-olds to 27% of the first graders, 54% of the fourth graders, and 90% of the seventh graders. A within-individual analysis comparing success patterns on the two parts of the transformation study revealed that children did significantly better on the questions about chunks than on those with powders. The results revealed confusion between functional object and material identities among some four-year-olds and uncertainty about whether chunks reduced to a powder retained their material identity.

During the "made of" interviews, four-year-olds, but few older children, responded by talking about parts of the objects rather than by mentioning materials. Reference to parts of objects was made by 50% of the four-year-olds in contrast to 18% or fewer of the children of older ages. However, 70% of the four-year-olds also made reference to material at some time.

A pattern analysis was performed that took into consideration all responses given when discussing both objects. Four patterns were identified: (1) don't know (no response to both questions), (2) object level (description of objects or mention of object parts at all times), (3) object/material mixture (reference to materials and to object parts), (4) material level (reference only to materials).

Four-year-olds were the only age where object-level patterns appeared, but they were infrequent. The object/material mixture was common among four-year-olds (40%), but not common among older children (18% or less). Four-year-olds were significantly more likely than first and fourth graders combined to fall into either the object level or the object/material mixture patterns. The material-level pattern was given by only 30% of the four-year-olds compared with 73% or more of the older children.

The researchers reported two points of transition during the ages studied between four-year olds and first graders, and between middle elementary-school children and junior high children. The changes in responses during the school years suggest development in children's concept of material from a perceptually based concept to a more abstract concept.

First graders used material classifications when appropriate, though their idea of material kind was not the same as an adult's. They had difficulties with powdered examples of materials. Powders were not sorted with chunks of the same kind on forced choice and sorting tasks. Continuity of material kind between chunks and powder was not often recognized on the grinding task. The kind of material is not seen as being in each discrete particle.

Children's ideas of material is analogous to the adult notion of cloth. Cloth is used to make objects like a shirt, and adults agree a shirt is cloth as a child agrees a spoon is wood. For adults, cloth ground into bits is no longer cloth, just as for children materials reduced to powders no longer hold the same material kind as when whole or in chunks.

Conceptual Change Strategies

Happs and Scherpenzeel (1987) reported a study that compared two different teaching strategies, one using conceptual change methods, and the other using a didactic method. The study was conducted in one Year 2 (seven-year-olds) classroom of 25 students in Australia. The topic of study was differences between monkeys and apes. The class was randomly divided into two groups, half of the class was taught using a didactic strategy, and the other was taught using a conflict and accommodation strategy building on the learner's prior knowledge about apes and monkeys. The conceptual change strategy used in the study followed four steps: (1) exploring student views about apes and monkeys and any perceived differences, (2) discussing students' views and comparing them to those held by zoo personnel, (3) providing a novel setting (Perth Zoo) in which learners might test the usefulness of a scientific understanding of apes and monkeys, and (4) reassessing the learners' understandings of ape and monkey characteristics and comparing the outcomes of expository and experimental groups. There was no description of the expository method of instruction.

Students in the experimental group were individually interviewed using an open-ended protocol. Students in the expository group were not interviewed for their initial ideas. The pretest indicated students in the experimental group held misconceptions about the differences between apes and monkeys.

The entire class of 25 students was taken to Perth Zoo one week after the preliminary interviews. The 12 students in the experimental group were taught by a Zoo Education Officer. It was stated the Zoo Education Officer discussed with the group their prior ideas and understandings about apes and monkeys. These ideas were elicited by general discussion and written on the blackboard. The expository group was taught by the author of the study. The instruction did not include a collection of student ideas.

Post instruction interviews of the students occurred at two months and 10 months following the zoo visit. All 25 students were interviewed during the posttest. The same pre-instruction test was used in the post interviews. Similar questions were asked in the post interviews. Two months following instruction, the experimental group, N=12, produced 143 correct responses to primate identification tasks from a possible total of 176. The posttest gave an 81% correct response rate in comparison to the 31% correct response rate prior to receiving instruction. The expository group, N=13, produced 142 correct responses from a possible total of 208, yielding a 68% correct response rate. It was unclear why there were different numbers of responses for experimental and expository groups. Ten months following instruction these correct responses had fallen to 70% for the experimental group and 47% for the expository group.

The researchers concluded that instruction building on students' prior knowledge proved successful for many students. They cautioned against believing that one particular teaching strategy is successful at producing conceptual change for all students.

Joshua and Dupin (1987) conducted a study in which they attempted to take into account student conceptions in planning instructional strategies to help change those conceptions. They examined methods for overcoming epistemological obstacles (change resistant conceptions) focusing on the study of electricity.

They conducted this investigation within two grade levels in France. Children were learning basic electricity at the sixth and fourth grade levels (USA grade equivalents 6 and 8). A total of 106 students were studied: 67 sixth-grade students representing three classes and 39 fourth-grade students representing two classes.

The procedures were two-fold, including interviews and classroom observations. During pre-instruction interviews, student ideas about electricity were identified.

Results from the interviews revealed four main conceptions of the problem given. The first was the "contact" conception. In this conception, contact between a battery terminal and one light bulb was enough to describe why the bulb lights. The second conception was the "single-wire" conception. In this conception, it was thought only one wire was needed to bring electricity to the bulb. In the third "clashing currents" conception, two currents leave the battery and supply the bulb without returning to the battery. In the fourth conception, the "current wearing out" conception, students acknowledged circulation, but believed the current "wore out" as it went through the bulb.

During the classroom discussions somewhat different results were found. There were no contact conceptions appearing in the classroom discussions. There was very little appearance of the single-wire conception. The researchers proposed two explanations: (a) a simple remark by the teacher may have led students to realize they needed to further their explanations, and (b) when students heard more sophisticated explanations by other students they recognized their own as crude and adopted the more sophisticated ones themselves. A reason not mentioned by the researchers could be that students holding those conceptions did not share them in class discussions. It is possible they still held those conceptions but did not make their ideas public.

To help students overcome obstacles blocking understanding, students were introduced to a "modeling analogy," or thought experiment, in the form of using a train representing a simplification of the mechanical analogy of electric circuits. From the report it appeared the researchers planned the lesson, but the regular classroom teachers carried it out. Following discussion around the analogy, students in both grade levels were able to recognize that the current stays the same in the circuit though the battery may wear out. The researchers claimed that in the face of the results of their study, instruction needs to build against natural conceptions which is not an easy task. A well-chosen analogy should help students develop their ideas toward correct conceptions.

Fleer (1992) sought to study young children's scientific understandings and the conceptual change that occurs during the teaching of science. She analyzed teacher/child discourse to identify interaction that facilitated conceptual change. She used three classrooms to investigate her questions. The three classrooms involved a Kindergarten room (5 year-olds), a Transition/year 1 room (5 to 7 year-olds), and a Year 2/3 room (7 and 8 year-olds). All teachers involved in the study described their approach to teaching science as interactive.

The researcher collected 100 hours of videotape and 190 hours of audiotape. The teacher's science lessons were video-taped and children were interviewed about their scientific understandings prior to, during, and after completion of the science units. The researchers analyzed the children's and teachers' discourse during scientific investigations in order to document successful interactional types that facilitate conceptual development in young children.

Fleer stated all three teachers used an interactive approach to science teaching. Children in the classrooms were encouraged to record their ideas and questions about what they were studying, were assisted by their teachers on their work, and were required to present their findings. For the Year 2/3 classroom an analysis of transcripts indicated that teacher-child interactions were procedural in nature. There was no follow-up on questions, nor inquiry into student findings. The interaction was more related to the teacher ensuring correct recording of questions and findings than individual thinking. An analysis of the Kindergarten classroom interactions showed the teacher attempting to extend student thinking through questions. The teacher used questions to focus their thinking, but the children seemed to see no connection between the questions she asked and their understandings of the concept of electricity. In the Transition/year 1 classroom the teacher seemed to have more success in helping her students develop concepts closer to the scientists' explanation of electricity. The researcher identified three factors from the transcripts that seemed to make this difference. First, the teacher held shared understandings of the children's ideas. In other words, the teacher sought to understand the children's ideas from their viewpoints, she did not strive to impose her ideas on theirs. Second, the teacher scaffolded the students' ideas through structuring the activities, modeling, and sharing the responsibility for the completion of the circuitry necessary to construct a flashlight. Third, a social framework was evident throughout the investigations. The framework provided a structure through which students conducted their investigations.

In addition, Fleer identified child-child interactions that influenced conceptual learning. In the Year 2/3 classroom child-child interaction occurred that did not influence conceptual learning. Fleer termed this a constructive/destructive dichotomy wherein there was no social framework evident, and thus provided few learning opportunities for children. In the Transition/year 1 classroom, however, the teacher established a social framework. She chose activities that were within young children's grasp, and enforced a rule that whatever was pulled apart is reassembled. The researcher claimed the rules made it more possible for the children to develop conceptual understanding because the teacher required them to develop shared understanding, scaffold their experiences and framed those experiences within a constructive orientation.

The researcher concluded it was not just that students engaged in discourse that was important, but rather it was the type of classroom interaction that influenced conceptual understanding of science. If teacher-student interaction was procedurally oriented, or if the teacher's questions lacked purposeful direction and shared understanding, students were unlikely to develop conceptual understanding. However, if teacher-student interaction showed evidence of shared understanding, contextualized learning, and purposeful activities, then conceptual learning took place. In short, the teacher's job was to choose the role of a fellow investigator rather than a source of all knowledge.

Flick (1995) conducted a descriptive study of the science instruction of a fourth grade teacher. The purpose of this study was to analyze how an experienced teacher blended expertise in language arts and reading with hands-on science to stimulate classroom inquiry. The researcher sought to describe the processes by which teacher and students converged on mutually relevant concepts that represented significant learning in science. Another outcome from the study was that when the researcher introduced the teacher to conceptual change literature related to the unit she was teaching the teacher adjusted her plans for future lessons. The sample consisted of one fourth grade class in a middle class neighborhood in a town of 50,000 people.

The researcher used a collaborative method that involved the teacher as part of the planning in the research. The procedure included 10 in-depth classroom observations of class sessions involving the teacher, her students, and invited guest speakers. The researcher also incorporated discussions with the teacher surrounding the planning of the research prior to and during the study throughout the school year. A discussion of conceptual change literature took place as it applied to her space unit, and 27 of the 28 students in her classroom were interviewed nine weeks after completion of instruction, about their concepts of gravity, relationship of earth sun and moon, and the shape of the earth. Interview results were compared to students in the Nussbaum and Novak (1976) studies.

Data included classroom observations, discussions with the teacher, notes from the lesson plan book, interview transcripts, transcripts from classroom debate, and selections from each student's writing were entered into computer files for analysis.

The researcher reported that during instruction, the teacher's goal was to help students generate ideas and not to pin down a specific concept. The researcher observed her efforts to help students generate these ideas through organized discussions that produced a variety of ideas. She wanted her students to generate ideas by discussing them. In addition, she used writing assignments for students to follow-up speakers and hands-on activities. The teacher emphasized shared meaning of ideas through student writing and classroom discourse. To focus her students' ideas toward "mutual relevance" the teacher used at least three strategies. First, she created opportunities for students to generate verbal statements about scientific ideas. Second, she allowed discussions and hands-on activities to proceed with sufficient depth that she could recontextualize discourse around science concepts. Third, students were given many opportunities to hear their peers discuss their own ideas and were able to agree or disagree with these ideas. This opportunity was highlighted in a classroom debate that also served as a final assessment. The debate pitted students in a discussion of whether the earth were round or flat. Students were required to provide evidence for their views. This debate was planned by the teacher after reading conceptual change literature provided by the researcher that indicated students persist in believing the earth is flat even in light of the evidence of its roundness.

The researcher summarized results by stating in a classroom where students are actively discussing and speculating on science, children's ideas look less like misconceptions and more like developing conceptions. This teacher's specialty in conducting discussions through her language arts background allowed students opportunity to expand on and share ideas. The teacher helped the students interact with science concepts through their language, though the empirical elements of the science may not have been highlighted as much as desired in this fourth grade classroom. However, by allowing students to participate in the experience of their learning rather than being overwhelmed by too much unfamiliar material students may find it more significant. Describing effective elementary science teaching and sharing the descriptions with teachers can show different ways elementary teachers can approach the subject and include it in their daily curriculum.

The Learning Cycle and Generative Learning Models.

Smith (1983) reported a case study in which the purpose was to analyze the changes that did and did not occur in the conceptions of a class of fifth-grade students as they progressed through instruction designed to change their conceptions of how plants get their food. The unit of instruction was from Chapters 3-6 of the Rand McNally SCIIS Communities unit that incorporates elements of conceptual change models, such as exposing children's alternative conceptions, holding discussions and debate over concepts and ideas, creating conceptual conflict in the students by having them explain events, and encouraging and guiding development of new ideas in accordance with accepted scientific conceptions. The inclusion of elements of conceptual change was accomplished through implementation of a learning cycle that consisted of three phases to encourage conceptual understanding. The phases included exploration (during which the students experimented with objects to see what would happen), invention (during which the teacher introduced a new concept as an alternative to the preconceptions held by the students), and discovery (during which students applied their new conceptualization). This conceptual change strategy within the study comprised six weeks of instruction in a fifth grade class at about three lessons per week.

Interviews of target students at five different points in the instruction took place. Other data included tape recordings of all lessons and transcripts of selected class discussions.

Though the researcher did not describe instruction, he stated the instruction was not successful in bringing about conceptual change. Seventy percent of the students incorporated the idea that plants make food into their conceptions, but less than 20 percent of them related this to the availability of sunlight. The making of food by plants was thought of as being in addition to taking in of food from the environment rather than as a replacement. Only one student in the class appeared to have accommodated to the conception goal.

The researcher sought to describe reasons the conceptual change strategy was unsuccessful for most of the students. The first area noted was that of "empirical ambiguity." In this area students may be confused about generalizations they should draw from the empirical data they collected during the activities. The second area noted was that of "ambiguity in discourse." The third area of note was that of "attacking the wrong preconception." In this instructional unit it was noted that students often think of water as being food for plants, but the researcher noted water's role was not addressed directly in the unit. Students may begin to think of light as a component of food for plants but do not necessarily give up the idea that water or soil are also food sources for plants. A fourth area noted was that of "loose framing of important issues." In this area, teachers were not using questions that appropriately developed ideas of the issues under study. Students were asked to provide evidence for their ideas, but their conceptions of evidence were not always appropriate. The researcher discussed that uses of generic strategies have some value in their prescriptive powers. They may increase the likelihood that students will learn as intended, but generalizing to many students is limited in value. A generic strategy was not sufficient to develop conceptual change in all students.

Renner, Abraham and Birnie (1988) conducted a study in high school physics classes to see whether all phases of the learning cycle were necessary for student learning. The study compared classes of advanced placement physics students' learning when different phases of the learning cycle were left out of instruction. Two general conclusions were reported noting that the exploration phase, with students simply manipulating objects, was not sufficient for conceptual learning, and any phase of the learning cycle can be substituted for if the remaining phases provide a thorough laboratory experience that requires discussion and interpretation of explorations. Under certain conditions the exploration and invention phases are the only ones necessary for conceptual understanding. However, it must be noted that these results are with high school students who are much different from primary students.

In a study similar to Renner, Abraham, and Birnie (1988), Butts, Hofman, and Anderson (1993) explored whether simple hands-on experience lead to conceptual understanding of floating and sinking in a group of five and six year old children. The phase of the learning cycle that was being explored was the discovery stage, and whether experiencing it would be enough for young children to develop an understanding of floating and sinking.

The specific questions asked in the study were: (1) are direct experiences with objects that sink and float adequate to help children change their predictions and explanations about sinking and floating? And (2) is an instructional experience in which children are confronted with discrepant events and given opportunity to explore new patterns of events adequate to help them change their predictions about sinking and floating?

Children in one elementary school were selected to participate for their contrast in age, gender and ability levels. Their ages ranged from five to seven, and ability levels ranged from high to average. Of the 131 students who participated in the study, 113 who were present for all interviews and instructional treatment were included in the results reported.

The study included a pre/post-test design with two instructional treatments for all students. Students were initially interviewed for their ideas about floating and sinking. During the interview they were asked to predict which of a collection of objects would float and which would sink. After they made their predictions, they were asked to tell how they thought floaters were alike and different from sinkers. They were then allowed to place the objects in the tubs and asked to sort them into two groups—floaters and sinkers. They were finally asked to tell what they thought was the difference between floaters and sinkers. Children were allowed to pick up the objects, and to talk about predictions from their viewpoints.

All children then watched the video "Drops" that focused on water, but not on floating and sinking. Children were then individually interviewed with the same floating and sinking protocols. Different objects were used and each child's responses were scored as in the pre-interviews.

After the second interview, children participated in a 30-45 minute instructional activity involving floating and sinking. Children were in groups of 20 during the activity, and had many opportunities to predict and explore which objects would sink or float. Predictions and results were recorded by the children on a class chart. Items were selected for children to test and predict so that contrasting size, shape, color, and hardness of objects were illustrated since many students believed these characteristics were the critical difference between sinkers and floaters. Following the investigation, children discussed what they believed made some things float and others sink. After figuring out a rule, they tested different items to see whether there were any contradictions to be found. When discrepancies were found, the children rejected the rule, and thought of another rule that better fit the pattern of the floaters and sinkers.

Following the instructional activities, each child was again interviewed using the same protocols with different items to test. The entire sequence of interview, video, interview, instruction, and interview, was accomplished during a three-week period of time.

To address the first research question of whether direct experiences are enough to help children change their predictions and explanations about sinking and floating, the researchers analyzed the number of children who moved from an unsuccessful first interview to a successful second interview. Since there was no instruction between the interviews, but only the children's manipulations and explanations of their experiences, it was assumed that the manipulations of the first and second interviews stimulated change in their thinking. The analysis indicated there was no significant difference in the proportion of students who were successful before or after the video experience. There was no evidence that simple manipulation of objects helped children build a concept of floating and sinking.

The second question addressed was whether instructional experiences in which students were confronted with discrepant events and given opportunities to explore new patterns of events were adequate to help them change their predictions and explanations about floating and sinking. An analysis was made to determine the number of children who moved from an unsuccessful second interview to a successful third interview.

Since there was direct instruction and discussion between the two interviews, it was assumed that manipulative experiences plus conversations were the stimuli of change in children's thinking. A significant difference between the proportion of students' accurate conceptions before and after instruction was found. There was clear evidence that instructional experiences and conversations do help five- and six-year-old children develop a clearer concept.

What do practicing teachers understand about the learning cycle? Marek, Eubanks, and Gallaher (1990) conducted a study to examine the understandings of high school science teachers' of the learning cycle in relation to Piagetian developmental models, and that relationship to classroom practice. They found that teachers with good understandings of the Piagetian model of development and the learning cycle were more likely to effectively implement the learning cycle in classroom practice. Teachers with misunderstandings of the Piagetian model and the learning cycle did engage their students in laboratory activities, yet were not successful in implementing the learning cycle, and their students did not construct scientific concepts. The authors noted that teachers with a sound understanding of the learning cycle did not ask questions concerning the meaning of data during the exploration phase. Teachers in this study who demonstrated a sound understanding reminded students to make careful observations, and their data were discussed at a later time, while those with partial and limited understanding of the learning cycle questioned students about their interpretations of the data.

Flick (1996) conducted a study of elementary teachers in which he described their developing understandings of the generative learning model (GLM). The GLM has origins in the psychology of Piaget and Dewey and observations about the nature of science. It assumes that students construct meaning based on their experiences, and interpretations of those experiences. It is similar to the learning cycle in that it presents an instructional strategy for the teachers to lead the students through, to help them make connections, construct meaning, and build on their own ideas. The researcher described the GLM as having five features to help students in forming concepts. These features include (1) students investigating questions based on their current understandings, (2) students reflecting on their current understandings, (3) as students are experiencing disequilibrium from their explorations, the teacher introduces a science concept that answers the question, (4) students reconcile their thinking with the scientific view, and (5) students apply the concepts to new problems that deepen their understandings. The researcher used a comparison of instructional process models (IPM) with which the teachers were familiar to the generative learning model (GLM). The IPM model presumed the most effective ways for instruction to proceed was to present lessons in small bits, give the students chance for guided practice, and then allow students to practice independently. Continual check for student understanding was necessary.

The subjects included all 24 teachers in a single elementary school with a large proportion of migrant farm workers and high population of low income students. The school was selected because the principal and staff were working on ways to make educational theory and practice respond to the social, economic, and cultural issues facing their students. The principal wanted the staff to balance skill-oriented instruction with teaching that encouraged higher-level thinking. Teachers were asked to reflect on the nature of the IPM and GLM models.

Several teachers wrote a grant to provide release time for two, all-day curriculum planning sessions for teachers at each grade level, K-5, to design a unit in science. Twelve sessions took place and served as the focus of the study. The main goal of the planning sessions was for teachers to develop a unit instruction. The format for the planning sessions was to (a) examine critical issues for fostering student learning in the school, (b) introduce a contemporary view of inquiry-oriented science and mathematics teaching, (c) initiate a critical discussion of GLM in relation to IPM, and (d) design a unit of instruction.

The researcher participated in curriculum planning sessions and wrote field notes to document the discourse, as well as made tape recordings that were later transcribed. The focus of the discourse was on the comparison of IPM and GLM strategies. Science lessons were observed within a variety of classrooms that represented a range of instructional approaches. Teachers provided the researcher with copies of their notes and drafts of unit plans

Discourse was analyzed using social semiotic analysis. All transcripts were transcribed, coded and narrative interpretations were made.

Results showed that teachers thought of GLM as an activity-based method, with an emphasis placed on the activities rather than objectives. Teachers had difficulty in defining measurable objectives they could measure. However, they felt positively toward including more activity in their classrooms, but viewed GLM as an inside-out or upside-down, version of IPM. They appeared to think of GLM as a backward version of IPM. Teachers noted the difference in assessment for IPM and GLM models, with assessing the inquiry-oriented activities being seen as most difficult. The teachers seemed to view GLM as process and noted the difficulty of assessing process. The view of GLM as process showed a misconception by the teachers of how the other phases of GLM, such as student discourse, provided sources for assessment.

The researcher noted the data supported that the teachers had sufficient content knowledge for elementary science teaching, and the GLM model highlighted their lack of confidence in teaching science. Teachers reported guilt and regret at not providing more science instruction. Teachers sometimes reported believing they needed more background knowledge in science to teach using the GLM model than the IPM model. Results showed that even though the teachers were encouraged and willing to learn to teach more and better science, it was difficult for them to make the transition to seeing GLM as a viable method for doing so.

Discussion

It can be safely assumed that all children come to the classroom with their own ideas, and teachers should be aware of their ideas to help children change them to be more scientifically accurate. Though conceptual change strategies have been studied to help children move their ideas toward the scientific convention, it is questionable how successful they actually have been. Of the studies reviewed in this section, only one described how the teacher who was aware of student ideas adapted her own teaching (Flick, 1995). In another study that included classroom observation of the conceptual change strategy, in this case, the use of the learning cycle, was found to be ineffective at producing changes in children's ideas (Smith, 1983). In many of the other studies it was assumed the teachers were implementing the researcher-imposed strategies in their classrooms. Often no classroom observations verified this implementation, and often the teachers were unaware of their students' unconventional ideas which calls into question how committed they could be to changing their students' ideas through the researcher-imposed strategy (Butts, Hofman, & Anderson, 1993; Happs & Scherpenzeel, 1987; Renner, Abraham, & Birnie, 1988) . Knowing students' actual conceptions would make a difference because assumptions teachers make about student ideas could be erroneous. What a teacher believes a student may know or understand may be very different from what a child actually knows. If a teacher does not know children's conceptions, she or he may be teaching past the conceptions without realizing it (Erlwanger, 1975).

It is also apparent that teachers do not always have a solid conception of the learning cycle nor other teaching strategies designed to help children change their ideas (Marek, Eubanks, & Gallaher, 1990). In addition, it appears to be no easy task to help teachers develop a facility for using more inquiry-oriented strategies designed to move children's ideas toward the scientific convention, even when the teachers wish to improve their science teaching (Flick, 1996).

However, the importance of understanding students' ideas remains to be seen. It is important for primary teachers to note student ideas of the world to help children to confront and modify their ideas. It would be informative to note how a teacher who is aware of student ideas develop his or her own strategies to help students change those ideas.

Teachers' Thinking and Teacher Knowledge

A way of thinking about teachers is a consideration of the teacher as a professional (Calderhead, 1987). Professionals in any field need to have a thorough knowledge of what affects their positions. For a teacher this notion includes teaching methods, curriculum, subject matter, behavior and development of children, including their erroneous ideas and possible ways to address them. Knowledge bases are gained from working with children in a variety of contexts with different materials, and is specific to different content areas. A professional teacher is oriented toward meeting goals. Goals include student learning, but are affected by parents, administrators, curriculum developers, government agencies, and possibly politicians. The outside parties influence teachers by determining which materials were provided for teachers to use, which curricular guidelines for teachers to follow, providing finance for schools to use, staff working conditions, and providing a perpetuation of beliefs of what constitutes good classroom practice.

In the rapid pace of the classroom, teachers are faced with complex problems for which they must make quick decisions. Competing demands may lead to cost-benefit compromises in what teachers do to help their students learn. Though they may believe it is best to teach in a certain manner, costs to teachers in time, energy, or other factors may deter their intentions. Calderhead (1987) pointed out that professionals make changes and learn from their experiences by reflection on those experiences, yet in the field of education there is little time to engage in reflective practice.

However, teachers who believe student ideas are important to know and address in teaching are more likely to recognize student ideas and use them in planning and implementing instruction. What teachers do is strongly influenced by what and how they think (Clark & Yinger, 1987). If teachers believe children's ideas in science are important to attend to during teaching, it is likely this belief will affect their teaching. How it affects their teaching has not been delineated. Studies are included in the teacher thinking section that describe the importance of teacher thought processes on teacher action and decision making.

Teacher thinking is necessarily linked to teacher knowledge. Shulman (1987) views teaching as a way for a more knowledgeable person to transform understanding, skills, attitudes, or values, into representations or actions that allow a less experienced person to develop an understanding of the concept. Thus, teaching always begins with a teacher's understanding of what is to be learned and how it is to be taught. Shulman (1986, 1987) further postulated several areas of knowledge that contribute to effective teaching. First, a teacher must have knowledge of the content to be taught. If the teacher does not have a good understanding of the content, it is unlikely she or he is able to create representations for the students to help them develop accurate understandings. Second, a teacher must have pedagogical content knowledge, ways of representing the subject matter to the students to make it comprehensible. Pedagogical content knowledge refers to particular types of subject matter knowledge for teaching. It includes an understanding of what makes learning of specific topics easy or difficult, such as misconceptions students may bring with them to different subject areas. Shulman (1986) acknowledged prior studies on student misconceptions. He recommended a continuation of research that studied the pedagogical understanding of subject matter as a way to pursue methods for changing student misconceptions. A third area of teacher knowledge is curricular knowledge, knowledge of the curricular tools a teacher has available to help students gain understandings in subject matter.

It has been found that primary teacher science content knowledge tends to be weak, and primary teachers may even hold the same erroneous ideas as do their students (Kruger & Summers, 1989; Lawrenz, 1986; Smith & Neale, 1989). Yet the question remains of how much science content knowledge a primary teacher must have, and the other types of knowledge that are necessary, to be effective at teaching primary science. This section on teacher knowledge includes studies describing science content knowledge, as well as the development of pedagogical content knowledge, of primary teachers.

Teacher Thinking

Reflection on ideas students express in the classroom could cause teachers to note erroneous ideas and adapt their teaching to take them into account. An experienced teacher may routinely recognize student ideas during instruction and adapt teaching accordingly. Experienced teachers may not be able to explain how children's ideas affect their teaching practice, though they may agree student ideas clearly make a difference in how the teacher approaches instruction. Routinization of practice in how student ideas influence teaching is similar to what professionals in other fields experience as they become more proficient in their work (Berliner, 1987). Routinization is an automation of procedures that may be imperceptible by those who use them, though they may be the basis for their expertise.

Berliner (1987) reported a study describing the difference between how expert and novice teachers use student work to inform their teaching. Expert secondary math and science teachers were identified by their principals. None of the teachers had taught fewer than five years. A second, novice group of less experienced teachers were identified—highly rated student teachers and first-year science and math teachers. A third group was identified. This group was called postulants and consisted of even less experienced teachers comprised of mathematicians and scientists from local organizations who wanted teaching certification but did not want to take education courses.

An experimental task was given to each of nine experts, six novices, and six postulants. They were each presented with the following scenario:

> Five weeks into the school year a teacher was assigned an additional class to teach. The previous teacher had left abruptly and classes were being distributed among existing staff members. The new teachers were given assignments that fit their specialties. They were also given short notes left by the previous teacher, a grade book with grades and attendance, student information cards containing background information on the students in the classes, corrected tests and homework assignments, and the textbooks (Berliner, 1987).

Teachers in the study were given 40 minutes to write a lesson plan for the first two days of instruction. They were instructed to do no more or less than they would actually do to prepare for a real class. All participants were observed through a one-way mirror as they planned. They were aware they were being observed. They were interviewed following the planning session.

The most notable differences were found between experts and postulants. Experts were less interested in remembering specific information about students than postulants. They did not spend as much time focusing on individual information cards but reacted more toward the cards as a whole to get a group picture of the class. They preferred to negotiate their own relationships with the children they were to teach.

The postulants gave serious weight to the individual student cards, sorting them into groups of "good kids" and "bad kids." They could give no real reason for sorting them, but simply believed it was something they should do.

Like experts, novices did not focus on individual student information but gave different reasons from the experts. Novices did not want to be biased by negative statements by previous teachers, whereas experts tended to wish to be detached from individual student information and more focused on the whole class implications.

Expert teachers were less likely to accept other teacher's assessments of students face value than novices and especially postulants. Expert teachers did read the selections but wanted to base their views of their students on interactions with the students themselves.

Concerning taking over the new class, expert teachers were more critical of the previous teacher than subjects from the other two groups. Expert teachers made suggestions for improving instruction in the class they were to take over, but novices and postulants were more interested in maintaining the status quo. The experts also had established routines for beginning the class and held different conceptions about the kinds of information students could provide them. The kinds of information students provided teachers was a critical point from this study. Postulants tended to simply want to know at which point the previous teacher had left off in the text. Novices also reviewed the previous lesson with the students to ensure understanding. However, neither group of teachers spent time eliciting information from the students. The expert teachers planned to hold discussions with students and had review exercises with the explicit purpose of assessing student knowledge of the subject matter. One participant stated he would not make specific plans for the first two days of instruction so he could use the time to interact with students and assess what they remembered so he could plan future lessons.

Wilson, Shulman, & Richert (1987) reported a series of research studies on representations of knowledge in teaching. Their studies began by using semi-structured interviews to develop intellectual histories of teachers. Teachers were asked to share their conceptions of subject matter and pedagogy. The interviews began with participants sharing stories of their education, highlighting experiences that influenced their current conceptions.

However, the researchers noted they still did not have an understanding of the knowledge the participants held. They began to use items such as free association and card sorts to uncover ideas about key concepts and principles of subject matter. The researchers had further conducted a series of "planning, observation, and reflection" cycles, during which teachers were asked to talk about their planning to teach a particular subject matter, focusing on their content knowledge and what they wanted their students to know. Lessons taught by participants were then observed. Following the observations, the researchers discussed the teaching episodes with the teachers, focusing on changes in knowledge of the subject matter, pedagogy, and perceived sources of those changes.

The researchers found that teachers generated representations, or transformations of the subject matter, intended to provide meaning and understanding for their students. These representations took many forms, such as metaphors, analogies, illustrations, examples, in-class activities, and homework assignments. The teacher created multiple representations, and the students invent their own as they experience the representational activity of the teacher. The activities provided by the teacher helped students develop their own representations.

The researchers described teachers needing to draw on many kinds of knowledge to provide appropriate representations for students. They must have knowledge of subject matter plus knowledge of the ways the subject matter is structured. They must have knowledge of educational purposes and other content from areas not within the discipline they are currently teaching. They require knowledge of pedagogy, or general strategies for teaching. They must have knowledge of the learner, including student characteristics and cognition's, as well as developmental aspects of how students learn. Teachers must also draw on knowledge of the curriculum to help them design appropriate learning activities.

The researchers also discussed the importance of pedagogical content knowledge. Pedagogical content knowledge included knowledge of the most useful ways to represent ideas to others, including knowledge of what makes learning certain subjects difficult, such as understandings of the conceptions and preconceptions children bring with them to the classroom. Teachers also require a repertoire of ways of taking those ideas into account when teaching.

The researchers described a way to think of the understandings teachers must hold. They must have a good understanding of pedagogical reasoning, beginning with a critical understanding of the subject matter. Then the teacher must be able to transform the content into a form the students can interpret. Transformation was composed of four processes, beginning with critical interpretation, or reviewing instructional materials in light of one's own understanding of the subject matter. Secondly, the teacher must have a repertoire of representations in the form of metaphors, analogies, illustrations, activities, assignments, and examples, to transform the content for instruction. A third area was adaptation, or fitting the transformation to the characteristics of students in general. Student characteristics influenced the ways they may represent material. Student misconceptions need to be noted and accounted for in order to tailor, or adapt lessons to specific students in one class, rather than to the student population in general.

Bromme (1987) discussed the importance of describing teachers' emphasis on understanding of learning in a subject area because this is the focus of a teacher's task. Teachers invariably described their work in terms of helping students understand various content subjects, so this validates studying teachers' accounting of student ideas in science. A teacher's knowledge of student understanding was a relationship between factual situations, persons, and objects. Thus, a teacher attending to student ideas looked for how students reacted in different situations and with different objects, in addition to how they respond to questions.

The researcher stated that developing student understanding is at the core of what a teacher does in his or her work. Thus, a teacher's ability to know what students understand is a key problem for investigation. His study sought to describe how many and what problems and progress in students' understanding are remembered by teachers if they are interviewed immediately after teaching and to find out who or what is the focus of recall.

To conduct his investigation, the researcher used interviews carried out following classroom observations. Questions focused on teaching goals and the motivational methods the teacher had chosen. These questions were to prime teachers to recall the teaching episode. These questions were followed by questions relevant to the investigation, such as: (1) Do you remember any subject-oriented learning progress made by individual students or groups of students? (2) Do you remember any subject-oriented mistakes or misunderstandings by individual students or groups of students? And (3) Were there any deviations and differences from your plan, and why?

Interviews were conducted with 19 teachers, who taught either fifth, sixth, or seventh grade, in one of five different schools. Each teacher was observed and interviewed on at least four occasions.

Data analysis included transcription of the interviews, as well as noting of comments made by teachers on other occasions. A system of categories was formed based on concepts. The categories showed similarities to the most important elements of stories. Interviews required verbal presentations of short stories about understanding. The researcher used the story structure of protagonist, event, and cause to provide an instrument to identify the relation of subject matter, students, and their activities.

Protagonists were the students involved in the study and events were the activities engaged in while learning the concepts. Causes of events were found by listing important variables of the instructional process and then coding what occurred in the classroom. Agreement between raters was 79 percent.

The most common events related to problems in understanding concerned students' difficulties with observable subject matter difficulties. For understanding student progress, subject matter insights were as frequently mentioned as observable activities. The most frequent deviations from lesson plan events were also student activities and insights into the subject matter.

The most commonly stated cause of events involving problems of understanding was the quality of instruction followed by student engagement and knowledge and skills. In reply to understanding progress, the most frequently named cause was students' motivation followed by teachers' instructional quality and students' knowledge and skill. The most frequently named cause for change in lesson plan was that the pacing of the class demanded the change. Teacher responses indicated they saw themselves as responsible for deviation from lesson plans.

Teachers tended to name groups rather than individuals when discussing protagonists in the classroom. Teachers had low recall of individual student problems and progress. Teachers recalled problems and progress in the classroom as whole-group responses, particularly when recalling problems. The recall of whole-group responses indicates teachers pay most attention to instructional flow as a group rather than individual dynamic. Individual contributions were remembered when they provided strategic value to the class as a whole. By strategic value, the researcher meant they occurred at moments when the lesson needed a new direction from the teacher's perspective. These responses could show understanding, or problems, students may have been having with the content.

Zahorik (1970) investigated whether a teacher who planned a lesson was less sensitive to students than a teacher who did not plan. Teacher behavior sensitive to students was defined as verbal acts of the teacher that permitted, encouraged, and developed students' ideas, thoughts, and actions.

Transcripts of lessons were obtained from a group of teachers who had planned a lesson and from a group who had not. Subjects were comprised of 12 fourth-grade teachers from four suburban schools. The teachers were randomly assigned to one of two groups—teachers who planned, and teachers who did not plan. Teachers who planned were provided with content objectives for a lesson they were to teach two weeks hence. The teachers who did not plan were not given a set of objectives. They were visited two weeks prior to the lesson delivery and asked to reserve an hour of class time to carry out a task for the researcher in two weeks. They were not told the nature of the task until a few minutes before they were to perform it. Both sets of transcripts were analyzed to determine teacher sensitivity toward students using a researcher-designed instrument.

It was found that teachers who engaged in more planning placed less emphasis in understanding students' ideas than teachers who planned less. The researcher theorized that teachers who had a more set plan wanted to cover what was in that plan and students interjecting their ideas disrupted the flow of the planned lesson. However, Zahorik gave alternative planning ideas by stating that teachers could add to their plans ways of addressing student ideas—a way of listing teacher behaviors the teacher wishes to use to influence student learning. Zahorik additionally stated that teachers with greater experience tend to internalize teaching skills and then unconsciously select teaching behaviors to address student ideas.

Huberman (1985) conducted an analysis of the knowledge that was most useful to teachers. He also wanted to find why these areas of knowledge were more useful than were others.

The researcher used a review of literature to create a list of what was most important for teachers to know. He then interviewed 60 secondary teachers to obtain their critique and revision of a list of 25 facets of teaching. The list contained nothing about understanding students' prior knowledge with the possible exception of bringing students up to grade level when they start the year below grade level. The findings focused more on management problems, developing relationships with students, having a variety of materials available for the students to use, feeling secure with colleagues, parents, principals, and other administrators, keeping one's wits in difficult moments, and accepting criticism well. The review did not focus on teacher's decision-making during classroom instruction.

Teacher Knowledge

Lawrenz (1986) conducted a study during which he explored elementary teachers' knowledge of physical science concepts. The 333 teachers who participated in the study were involved in a physical science inservice training program. The program consisted of classes in science content and science classroom activities that were offered in eighteen different school districts. All teachers completed a teacher questionnaire and a Physical Science Test (PST). The questionnaire included demographic information and the PST was used to assess the existing state of knowledge about physical science. The PST was given before the course began.

The distribution of teachers was fairly even from K-9, with the majority of the teachers coming from the sixth grade. Most of the teachers taught in self-contained classrooms. The teachers within this study were biased toward science. They had voluntarily enrolled in a science course and reported teaching science often.

The teachers understood some of the physical science concepts, but not others. The number of teachers answering each of the 31 items correctly ranged from 90% for one item to 34% for another. More than 50% of the teachers responded correctly to items about atomic structure, off-center balancing, averaging, lenses, batteries, density, stars, heat exchange, and chemical reactions. Eleven of the items were answered correctly by 50% or less of the teachers. Some of these items were fairly content specific or fact oriented, and missing them may have been due to lack of information or unfamiliarity with terms.

Other items did not require specific content knowledge and seemed indicative of misconceptions. Teachers appeared to have misconceptions regarding the mass of gases. They believed that adding more gas to a balloon would not increase the volume. Teachers also had a misconception about motion. Thirty-six percent of the teachers believed that one ball would continue to move after directly hitting another one. They even described in which direction the ball would move.

The teachers in this study had strong educational backgrounds, with 47% holding masters degrees, and had positive attitudes toward science. However, they did not do well on the exam overall, and appeared to harbor misconceptions concerning several areas of physical science.

Kruger and Summers (1989) reported results of a study in which they interviewed primary teachers for their understandings of changes in materials. Nineteen primary teachers from 5 primary schools in England were given in depth interviews concerning their ideas of energy, materials, and forces. The interview-about-instances technique was used. Initial focus questions were asked about drawings on cards, each depicting an instance of the particular scientific concept under investigation. Additional questions were posed according to the responses given by the teachers.

Few teachers referred to molecules in their responses of change in materials. Often teachers could use scientific terminology, but were using it incorrectly. Teachers did not have an accurate scientific conception. The teachers' ideas were compared with children's ideas and were found to be similar.

Though it is unlikely that primary teachers would be instructing their students in the concepts of molecules, it is also the case that teachers need to know more than their students. The teacher needs to have a deeper understanding of science than the students in order to appropriately guide students' developing conceptions.

Kruger, C., Palacio, D., and Summers, M. (1992) described a study that explored primary teachers' understandings. They used this information to develop teacher education materials.

In-depth interviews were conducted with 20 primary teachers in which discussion about concepts in the above three areas was stimulated by cards depicting familiar situations, or by demonstrations using the interview-about-instances technique to probe for understanding of science concepts. These early interview results were used to develop a questionnaire that was give to 450 primary teachers. There was a 100% return because the questionnaires were given in person and collected upon their completion.

All teachers who participated in the research were volunteers. Most teachers had had little formal training in science since their own secondary education. When they had participated in formal training, it was generally biological rather than physical science. They were motivated to teach science in their classes. Most taught children aged 6-8, but there were some who taught ages 7-11.

Results showed faulty understandings of physical science concepts. In the area of forces, for instance, over 50% of the teachers did not recognize that a table or the ground is considered to exert an upward force on objects. Teachers had similar misconceptions in the areas of materials and energy.

A comparison was made to see whether teachers who had studied physics in high school had a better understanding than those who had not. The comparison yielded no significant differences in the number of correct responses to any of the instances where the analysis was possible. Of those who continued in their study of physical science through high school, there was no improvement in their knowledge of physics. Those who had studied physical science were as likely to harbor misconceptions as those who had not.

Smith and Neale (1989) reported a study in which they described how a group of 10 elementary teachers progressed through a course of study designed to help them teach science using conceptual change strategies. The program's main goals were to help teachers improve their content knowledge as well as their knowledge of children's ideas, and views toward teaching science.

Data included videotapes of the teachers' spring and summer lessons that were transcribed and coded for features that indicated conceptual change teaching. In addition, teachers were given instruction on interviewing children, and were required to interview a child of age 5-8. Their interviews were audio-taped. Two researchers independently read questionnaires and interviews and noted evidence of the teacher's orientation to teaching and learning science, content knowledge of science, and knowledge of children's ideas. Disagreements were few and were resolved by discussion between the raters.

The researchers found that teachers' content knowledge was limited in science in general, and specifically in the physics of light and shadows. Many teachers exhibited the same misconceptions as their students. Teachers commented that they enjoyed the physics activities, though at first they were intimidated. They mentioned the time it took to "sort out" the meanings of situations. They demonstrated an improved attitude of their abilities because they were able to figure out what they needed to know.

In terms of pedagogical content knowledge, at the outset of the project few teachers focused on children's ideas, predictions, and explanations. When they did try to respond to children's mistaken ideas they usually simply corrected the ideas and tried to explain in more detail. Children's explanations for their ideas were not generally sought by the teachers. Most teachers remained unaware that children's ideas could interfere with their understandings of concepts. Most teachers did not adjust lessons to address children's ideas, but continued the lesson as planned.

However, following the summer workshop, three teachers made important changes in their uses of conceptual change teaching strategies. The three teachers who made the changes began to focus on scientific concepts, elicit student preconceptions by asking for predictions and requiring explanations, by probing and asking for clarification of ideas, by asking children to test ideas, and contrasting alternative ideas with one another, and asking children to apply their ideas to new events.

Central to making the changes in science teaching was the improvement in teachers' knowledge of the content, their translation of that content into appropriate and flexible usage in lessons, their knowledge of children's likely preconceptions to be encountered in lessons, and of effective teaching strategies for addressing them. Especially important were their beliefs about the nature of science teaching.

Neale, Smith, and Johnson (1990) conducted a study related to that above, wherein 10 K-3 teachers were trained in conceptual change teaching strategies and then tracked to see how well they were able to implement conceptual change teaching in their classroom instruction.

Prior to implementing the program to instruct the primary teachers in conceptual change strategies the researchers identified the following characteristics of conceptual change teaching:

1. Instruction is directed toward the contradiction of misconceptions held by students and toward the development of scientifically accurate models.

2. Instructional episodes are linked conceptually to prior lessons and children's experiences.

3. Instruction elicits children's conceptions.

4. Activities are provided in which children test their predictions, discover contradictory evidence, and contrast alternative explanations and conceptions, including appropriate scientific models.

5. Children represent their own thinking in several modes, and the teacher checks their representations. Children share their ideas with the teacher and others, and debate ideas.

6. The teacher helps children summarize experiences, highlights and contrasts alternative views, and requests explanations that examine the evidence available to support each.

The researchers used the above characteristics to revise an Elementary Science Study unit on light and shadows. The revised unit was designed to address common misconceptions children have about light and shadows, and provide activities so children could construct more accurate scientific content.

Additionally, the researchers analyzed an expert teacher present the 13-day unit to several classes of children in a K-3 laboratory classroom. The analysis allowed the researchers to describe and document the subject-matter and pedagogical knowledge required for successful teaching of the unit.

Ten primary teachers, two kindergarten, six first grade, and two third grade, participated in a federally funded institute on primary science instruction. These teachers participated in a four-week summer institute on primary science. The instructor was a science educator and experienced primary teacher who had developed the unit. Teachers were video-taped prior to participating in the institute, and were interviewed to assess their knowledge and beliefs about science and science teaching, as well as light and shadows.

During the institute the teachers confronted their own ideas about student thinking and practiced eliciting children's ideas by teaching a portion of the unit to a group of children in a summer science camp. Each teacher was video-taped teaching the unit to the group of students. Teachers also tested their own misconceptions about light and shadows in activities that elicited their ideas and provided opportunities to confront and modify them. Teachers had time to discuss in small groups what they were learning about light and shadows, and about teaching for conceptual change. They made regular entries of their reflections in journals. In the concluding week of the institute, teachers interviewed children again about light and shadows to assess the progress made during the unit. They received time during this week to plan a two week unit to be taught the next year in their own classrooms.

During the academic year, monthly meetings were held to continue reading and thinking about light and shadows, about teaching for conceptual change, and plans for an instructional unit. When taught, units were monitored by the instructor and video-taped. Teachers also kept journals of their experiences.

Data included viewing the video-taped lessons, interviews of students before and after the unit was taught, teachers' own self-evaluations, and interviews with the teachers. Teachers were categorized on different features of conceptual change teaching as showing either (1) no implementation, (2) partial implementation, or (3) high implementation.

These features were measured by the use of a Configurations Checklist Rating that tracked teacher behavior in the categories of conceptual change noted above.

Each of the teachers made substantial progress in implementing conceptual change teaching. Differences between mean ratings before and after training proved to be statistically significant for the group, as indicated by the Wilcoxon signed-ranks test ($z = -2.20$; $p = .028$).

Teachers were better at eliciting and identifying student misconceptions, and in presenting discrepant events than in helping students construct new knowledge. Teachers who were rated as high implementers were successful in getting students to make predictions, but low implementation was noted on applications to everyday experience. Teachers had success in providing appropriate activities and materials and in managing their classrooms.

Eight of the 10 primary teachers who attended the summer institute were able to implement a conceptual change unit on light and shadows in their classrooms the following school year. Implementation varied, but results indicated that primary teachers can use conceptual change strategies successfully.

Results indicated teachers had to make strenuous efforts to construct the knowledge required for this type of teaching. The subject matter knowledge did not come easily for most teachers.

Stoddart, Connell, Stofflett, and Peck (1993) conducted a study in which they described a procedure for improving the science content knowledge of elementary teacher candidates. They conducted the study within math and science instruction. Similar procedures were carried out for both the math and science portions. The science results have bearing on the current study, and so are reported here.

An analysis of the entry-level content understandings of elementary teacher candidates after completing subject matter courses was conducted. An analysis of the effects of a conceptual change unit on elementary teacher candidates' understanding of science content was also conducted. The study took place in a setting of existing teacher education methods classrooms.

The science sample included 59 subjects, 46 females and 3 males with a mean age of 23 years and 7 months. These students were enrolled in three science methods courses. The students enrolled in the conceptual change classes included all students enrolled in the methods courses. There was no control group available for study.

All teacher candidates were administered paper and pencil content tests in science on entry to the elementary education courses as part of the instructors' assessment of students' preconceptions. The test covered topics on the weather cycle because this concept was included fairly consistently in elementary curricula. The test contained 12 open-ended questions designed to allow students to explain from their viewpoints. Student responses were classified into three categories: (1) naive conceptions, (2) scientifically naive conceptions, and (3) scientific understanding. Naive conceptions included responses that reflected no scientific understanding. Students with scientifically naive responses used scientific terminology in their explanations, but used the terminology incorrectly. Those classified as having scientific understanding were complete responses that corresponded to the scientifically accepted explanations for the phenomenon. On entry to the class 49% of the novice teachers' held naive conceptions, 36% scientifically naive, and only 14% demonstrated scientific understanding. Their understandings of the science content was similar to that of the elementary school-age children they would be teaching.

The intervention included having the teachers participate in a conceptual change unit as taught by their science methods instructor. The science content was the water cycle, specifically the change in the state of water as it occurs under normal atmospheric conditions. The content was taught using the five steps of conceptual change as noted below:

1. eliciting preconceptions
2. guiding explorations of phenomena including disconfirmatory experiences
3. questioning and discussion to lead students to scientifically accepted perceptions.
4. comparing new conceptions to original ideas to create disequilibrium.
5. applying new concepts to real world situations.

Teacher candidates took the science content assessment at the end of the 10-week period of instruction. At the conclusion of the unit 69% of students demonstrated scientific understanding. Only 31% were naive or scientifically naive. The conceptually based science content unit significantly improved the teacher candidates' understanding of what they would teach students. The participants in this investigation had taken three undergraduate mathematics and three undergraduate science course as a part of their degree. The majority of the students had GPAs in the upper quartile of their class. It is clear that the traditionally taught courses were ineffective in developing candidates' conceptual understanding of mathematics and science.

The elementary teacher candidates in this study dramatically improved in their content knowledge after being taught through conceptually-based teaching methods. Results indicated that it was not academic incompetence that limited elementary teacher understanding of science content, but rather the pedagogy used to teach the subject matter they were learning that limited teacher understanding. Conceptual understanding of the subject was a necessary if not sufficient condition which underpins conceptual teaching. Teachers unable to explain their own reasoning were unlikely to help students develop understanding of the science content.

Discussion

From the studies reviewed, it is apparent that primary teachers have weak content knowledge (Kruger, & Summers, 1989; Lawrenz, 1986). However, this content knowledge and pedagogical content knowledge can be improved by primary teachers participating in science explorations taught by conceptual change methods (Neale, Smith, & Johnson, 1990; Smith & Neale, 1989; Stoddart, Connell, Stofflett, & Peck, 1993). Teachers who received instruction in science using conceptual change methods began to focus more on their own students' thinking (Smith & Neale, 1989). It is possible that methods being used to introduce science to primary teachers do not provide opportunities for teachers to develop the content knowledge, or the pedagogical content knowledge required to teach science conceptually to young children (Stoddart, et al, 1993).

Several points can be drawn from the research on teacher thinking that inform the current study. First, teachers tend to focus on a group picture of their classroom, rather than individual understandings within their classrooms (Berliner, 1987; Bromme, 1987).

Berliner found that experts were even better at focusing on the class group as a whole than were novices or postulants. The teacher expertise provides evidence that it is more effective for teachers to assess and change student understandings and conceptions as a whole group rather than individual students. Bromme (1987) noted that when teachers were describing what students understood, or did not understand, they tended to focus on the whole group, rather than the individual. However, an individual's input was noted, particularly when that input provided a direction for the lesson to proceed.

Second, Wilson, Shulman, and Richert (1987) found that in order to teach, teachers attempt to transform their knowledge into a form comprehensible by students. They use many methods for transformation, such as analogies, explanations, homework, and activities. Elementary teachers can become better at transforming science content to a form their students can comprehend when they receive instruction that enables them to see the value of such instruction (Neale, Smith, & Johnson, 1990; Smith & Neale, 1989; Stoddart, Connell, Stofflett, & Peck, 1986). Berliner (1987) found that expert teachers also elicited student knowledge, that assisted them in planning the transformations to help students understand new content.

However, implications of planning must be addressed. Zahorik (1970) found that teachers who placed less emphasis on planning were more likely to take into account student ideas. Teachers who spent more time planning focused more on getting through their plans. They were less likely to allow student input to detract them from their plan. A way around concluding that being well-planned means not attending to student thinking is to help teachers note in their plans ways to draw out, or account for student ideas.

Child Psychology

Children of primary age do not have the same logical thinking, nor background experiences, as adults (Piaget, 1929; Vygotsky, 1986). For this reason, it is necessary for primary teachers to have a solid knowledge of the psychology of young children. If the teacher does not have an awareness of the developmental abilities of the students in the class, instruction may not match the student. For instance, the teacher could present lessons past the abilities of the students, prohibiting their learning of the concepts. The teacher could also present lessons below their developmental levels. Failure to challenge them appropriately prevented students from learning and building on concepts. The instruction must match the developmental levels of the students, and the teacher must also be available to help the students attain concepts for which they are capable. The studies reviewed in this section are empirical work surrounding cognitive development of young children. The children are generally of primary age (5-7), though some studies include children of older and younger ages.

It is important for teachers to note the developmental abilities of their students when identifying their ideas. Children of primary age have abilities that enable them respond to teacher queries in certain ways. The ways children respond can alert teachers to student thinking, but unless the teacher has knowledge base about her students she may miss important cues to their thinking. Understanding how children of primary age can typically respond also helps the researcher identify when children are expressing their ideas. Piaget (1957) stated that young children cannot develop ideas from pure experience or empirical truths given them apart from logical relationships that appear as a group of operations. These operations are not fully developed in children of primary age, but experiences and directives provided them can help them acquire these operations. Children begin to develop operational thought through symbolic play in which they are able to pretend and re-enact events they have seen. The symbolic play helps them to develop mental imagery that develops their thoughts. Piaget and Inhelder (1969) claimed that children's drawings were partially symbolic play and partly mental image. Children tend to imitate the real through their drawings, even drawing two eyes on the profile of a face because real faces have two eyes. Drawings can provide insight into children's thinking.

Most children of primary age have little knowledge of true causality (Piaget & Inhelder, 1969) . They are in the category of precausality. Often their explanations for why things happen include references of animism (in which all things are thought to be animate) and artificialism (in which things are thought to happen for the purposes of humankind). Ammon (1981) described the development of the notion of causality as one that is a lifelong task. She stated that even young children have some notion of causality which gets more defined as children grow older.

Forman and Kuschner (1983) argued that teaching young children should take into account their developing ideas and levels of understanding. Young children should have experiences that cause them to notice the way things in the world work, how things transform and change with or without the child's influence. Piaget and Inhelder (1969) stated that operational thinking is the ability to know these transformations and their reversibility. Students must have knowledge that some feature of the system remains constant in order to allow reversibility. Lawson, Abraham, and Renner (1989) agreed, stating this knowledge is impossible without the social influence of others, such as other children or an adult to help guide the student into noticing something interesting about the world. This guidance should be given at a moment in time that the student is prepared to accept it, and it should appear to be the child's own idea to notice the change or transformation. The teacher should intervene by also interacting with materials in a way that is modeling something the teacher wishes the child to try. The teacher should not force the child to manipulate the materials in such a way, but if the child follows the lead, the teacher should continue exploring and suggesting other ways of looking at the materials (Forman & Kuschner, 1983). The giving of guidance at critical moments is similar to Vygotsky's (1986) notion of the zone of proximal development. Vygotsky found that problems students were able to solve on their own were at levels lower than they could solve with the help of a more experienced individual, be it child or adult. He defined this difference as the "zone of proximal development" and said it was the difference between the mental age of the child and the age level at which the child could solve problems without help.

Vygotsky (1986) speaks of conceptual development in terms of pseudoconcepts, or concepts children are developing. His research found that concepts corresponding to word meanings are not spontaneously developed by a child, but rather, "the lines along which a complex develops are predetermined by the meaning a given word already has in the language of adults (p. 120)." In other words, young children develop a conception of an idea based on a word given by adults, or learned from adults, that is different from the meaning the adult holds of the word. It is through further experience with the word and its meaning that children can build beyond the pseudoconcept to a conceptual understanding that agrees with the adult's.

Vygotsky further states that young children do not have the ability of self-reflection on their own knowledge. He states school instruction can influence children's perceptions of their knowledge, and thus help students, even young students, become more reflective about their own knowledge. It is unlikely for students to develop this awareness on their own. Vygotsky found that instruction is often meaningless to students at first, until they have a reason to use the information and ideas they are learning. Instruction can become more meaningful from a child's reflection on his or her developing knowledge.

Nelson (1986) described a method for studying children's developing conceptions by using event knowledge. Event knowledge consists of using children's descriptions of real-world events to make inferences of children's cognitive developments. Children can use representations of events as ways of presenting evidence of their knowledge. Everyday events can show children's cognitive competence better than tasks given them by experimenters. Thus, interviewing children about their event knowledge of everyday occurrences can provide insight into their thinking. Real world knowledge comes to children almost exclusively from direct experience. Children's descriptions of their direct experiences provide evidence of their knowledge.

Child Psychology Studies

Wales, Colman, and Pattison (1983) explored an adult's role in helping children learn names of objects or in creating categories. The adult in this study who was paired with the child was always the child's mother. The definition of "category" within the study was a group of objects that were considered equivalent and were designated by names. The study explored how the mother helped the child learn the names of objects by placing them in categories. Forty mothers and their children were subjects. There were twenty 2-year olds and twenty 4-year olds, with equal numbers of boys and girls in each age group. All 4-year olds were attending a Kindergarten, and 15 of the 2-year olds were attending a day care creche. All subjects were tested in their own homes, with sessions lasting between 1 and 2 hours. In each session four separate naming tasks were completed. Each mother was involved in three of the four tasks, and each child was involved in two.

The stimuli were photographs of 36 common, concrete objects from the taxonomies of fruit, clothing, vehicles, and furniture. The basic categories represented in the pictures were FRUIT: apple, melon, berry; CLOTHES: shirt, hat, and shoe; VEHICLES: car, bus, and truck; and FURNITURE: lamp, chair, and table.

The guiding question was to examine whether subjects were sensitive to the communicative demands associated with different presentation contexts in object naming tasks. It was of interest to the researchers whether mothers and children altered their levels of reference in response to demands of contexts.

There were five different formats in which the item or items to be named were presented:

1. As a single basic level item (e.g., an apple).

2. A basic level item presented in the context of two other items from the basic level category, but from different subordinate categories (e. g., an apple such as a Granny Smith, in the context of two other apples—a Jonathon apple and a delicious apple).

3. A basic level item presented in the context of two other items from the same taxonomy but different basic levels (e. g., an apple in the context of a berry and a melon).

4. Three items from the same basic level category presented in the context of three items from three other taxonomies (e.g., three apples in the context of a vehicle, a piece of clothing, and an item of furniture).

5. Three items from the same taxonomy, but from different basic level categories presented in the context of items from three other taxonomies (e.g., for the fruit taxonomy, an apple, a berry, and a melon in the context of a vehicle, a piece of clothing, and an item of furniture).

The naming tasks were structured so that the proportions of names at the different levels of abstraction required to identify the pictured items were similar. For the seven kinds of variables there were four instances where superordinate names could have been used, four instances where subjects could have used basic level names, and three instances where a subordinate level name was appropriate to identify the pictured item.

Two different orders of presentation for the total of 52 different contrast sets were constructed so the order in which the five presentation conditions and the items representing particular category levels and taxonomies were counterbalanced.

In each of the 40 experimental sessions there were four separate naming tasks completed.

1. The mother named the items for her child of either 2 or 4 years (M-C task).

2. The mother named the same set of items for the experimenter (M-E task).

3. The child of either 2 years or 4 years named the same items for the experimenter (C-E task).

4. The mother told the experimenter the names she thought her child would use when naming each of the same set of items M-Prediction task).

The latter two tasks were independent. For each M-C pair these two tasks were completed first and second, with the order of presentation being randomly varied. The mother was absent from the room when the child was naming the items and the mother was interviewed alone for the M-E task. The M-C and M-E tasks were completed next. Half the mothers of the 2-year olds and 4-year-olds named the items for their children first. The other half of the mothers named the items for the experimenter first.

In each of the naming tasks, subjects were asked to give the name of the item or set of items the experimenter pointed to in each of the different presentation sets. It was indicated that labels rather than detailed descriptions were required. For the M-Prediction task, mothers were asked to give the name they thought their children would know and use when referring to the same pictures of objects.

The experimenter noted whether the name given by the mothers and children was the superordinate, basic level, or subordinate category name, or some other term of reference. The first term of reference used by the subjects when naming the various pictured objects were the names recorded for those items. Any subsequent names given for a particular item were ignored.

For analysis, subjects' naming responses on each item were recorded and their responses on each of the variables were classified into one of four response categories:

1. basic level response
2. subordinate level response
3. superordinate

4. don't know/other responses

Since there were relatively few of the latter category responses 3 and 4 were pooled for the analysis of the mothers' responses. The researcher used a three-factor analysis design with repeated measure to analyze presentation condition and taxonomy, but not the factor of age.

The technique provided a test of significance for each main effect and interaction in the design by the construction for each effect, of a statistic Q_c having a chi square distribution. The data for the M-C naming task was analyzed separately from the M-E data since it was not possible to analyze repeated measures and non-repeated measures of the same factor (age) together.

Mothers of both 2- and 4-year olds conformed with expectations by naming pictures of concrete objects using mostly basic level names. The percentage number of basic level responses were 48 for 2-year olds, 42 for 4-year olds; subordinate responses 26 and 33%, and superordinate/other 26 and 25% respectively. The two independent groups of mothers were significantly different ($X^2(2) = 7.28$, $p < .001$).

The context of each presentation condition was an important factor in determining the mothers' choice of category names. For the presentation condition where a basic level name was required to identify the pictured objects, virtually all the names given by the mothers of both groups were at the basic level of abstraction. For the contrast sets where a subordinate level name was necessary to distinguish the items, mothers of both 2- and 4-year olds used considerably more subordinate level names than basic level names. For those presentation sets where a name at the superordinate level of abstraction was required, mothers of children of both ages were using predominately superordinate terms when naming the items for their children.

When naming items for which names at any of the three levels of abstraction could have accurately identified the items, and items for which either a basic level name or a subordinate name distinguished the pictured items, mothers naming items for their 2-year olds used approximately equal numbers of basic level and subordinate level names. For both variables the mothers' naming for their 4-year old children used considerably more subordinate names than basic level names. When naming items for which either a superordinate or basic level name was appropriate, mothers of both 2- and 4-year olds overwhelmingly chose basic level names when naming items for their children.

Analysis of the M-C data was conducted of comparisons that could contrast possible differential effects of context. Six analyses were of major interest, evaluating the effects of taxonomy, age, and one of the following six comparisons among context conditions:

1. Comparison 1: Investigating whether an item presented singly or in the context of two other items from the same category influenced mothers' choice of reference. This comparison was significant in the areas of age comparison ($p < .001$), comparison taxonomy ($p < .001$), comparison ($p < .001$), and taxonomy ($p < .001$).

2. Comparison 2: Examining mothers' naming for an item presented singly and for an item presented in the context of two other items from the same taxonomy but different basic level categories. This comparison was significant in the areas of age comparison ($p < .001$), and taxonomy ($p < .001$).

3. Comparison 3: Examining mothers' naming of single items presented in the context of either two other basic level category items or with two other items from the same taxonomy but not the same category. This comparison was significant for age/taxonomy ($p <.05$), comparison/taxonomy ($p < .001$), age ($p < .05$), comparison ($p < .001$), and taxonomy ($p < .01$).

4. Comparison 4: Examining mothers' naming of a group of items from the same basic category or such a group in the context of three items from three other taxonomies. This comparison was not significant.

5. Comparison 5: Examining mothers' naming of a group of three items from the same taxonomy but different basic categories or such a group in the context of three items from three other taxonomies. This comparison was not significant.

6. Comparison 6: Examining mothers' naming of a group of three items in the context of three items from three other taxonomies, where the target group was from the same basic category or different basic categories. This comparison was not significant.

Results of the M-E data showed that mothers' naming responses were predominantly at the basic level of abstraction. The percentages of subordinate level names used by mothers was greater when mothers were naming items for the experimenter than when naming for 2-year old children. However, there was almost no difference between the percentage of subordinate names used by mothers when naming items for the experimenter and for 4-year old children. Mothers used only a slightly greater percentage of superordinate names when naming the various items for the experimenter. Mothers used approximately the same percentages of basic level category names when naming for the experimenter and for 4-year olds.

An examination of the children's own names in these tasks makes it clear a substantial majority of names are at the basic category level. For the 2-year olds there were nine subordinate level responses, zero superordinate, and 133 don't know/other. The 4-year olds used 69 subordinate, 16 superordinate, and 71 don't know/other responses. The data suggest that some of the 4-year olds are sensitive to the communicative demands associated with the different presentation contexts. In looking at differences by taxonomy, that of FRUIT stands out differently from the others. For the 4-year olds 31 of the 69 subordinate responses were made to fruit.

Data also indicated that mothers of 2-year olds accurately predicted their children would overwhelmingly use basic level names when naming the pictured objects. However, the mothers greatly overestimated the number of superordinate and subordinate names their children would use when naming the objects.

For the 4-year old group, though the mothers correctly predicted their children would predominantly use names at the basic level of abstraction in the naming task, they underestimated the actual number of basic level responses their children would use. The mothers of 4-year olds slightly overestimated the number of subordinate terms that would be used, and greatly overestimated the number of superordinate responses their children would give. There was divergence between mothers' naming practices for their 2- and 4-year old children, and the children's actual naming responses and the mothers' predictions of their children's naming responses.

The researchers concluded that, as expected, the dominant strategy in the naming tasks was to use the basic level term. The most interesting results stem from conditions that deviate from this tendency. A most striking result is the difference between mothers' predictions and the children's naming responses for both the 2 and 4-year old children. The mothers' predictions were at variance with their child's naming.

The majority of superordinate names used by the 4-year olds were given when naming the sets of items in the context that required superordinate names to identify them. Their uses of subordinate items were similar in their context dependence. At age four children have already developed sensitivity to communication in different contexts. Mothers' selection of names at the superordinate level was almost entirely context dependent, whether naming items for an adult or for their child. Thus, the mother expected the child, as well as the adult, to be able to understand the naming within the context. Mothers did use more specific names with older children, indicating they believed older children could understand at a more advanced level.

Golomb and Cornelius (1977) conducted a study to explore the relationship of children's symbolic play and cognitive development. Their study employed 30 children between the ages of 4 and 4.6 years, with a median age of 4.3 years. There were 15 subjects in the control group and 15 in the test group. Each group had eight females and seven males. The groups were matched for age, sex, socioeconomic background, and type of schooling.

All students were given conservation pretests to see whether they could conserve quantities. It was established that all students could not conserve quantities of clay or liquid. The same tests were given as posttests following the investigations.

Students in the experimental group were given six pretense play situations over the course of three days. Two games were presented each day, in the same order to all children. All situations required children to pretend an everyday item functioned as another item. In each case the examiner challenged the pretense or carried the pretense beyond reasonable bounds. The child was thus maneuvered into explaining pretense play as a reversible transformation.

The control group children engaged in three play tasks over the course of three days. The play tasks did not require the children to pretend or imagine. The examiner carried on a relevant conversation with the child concerning the task.

Results showed that the symbolic play training group scored a total of 54 points, indicating 27 correct conservation judgments and explanations. The constructive play group scored only eightpoints, representing only four correct conservation judgments, all given by a single subject.

The results show a distinct improvement in the conservation performance of the experimental subjects who underwent symbolic play training. Their achievement was not matched by the control subjects. The finding that symbolic play facilitates conservation suggests a similar process underlies both phenomena. The researchers postulated that perhaps the similarity lied in the ability to maintain the identity of the object in spite of its transformation. They stated that within the symbolic play sessions, the child was allowed to discover within him or herself the solutions to the confrontations presented by the examiner. Without the examiner's confrontation during the symbolic play sessions it is questionable whether the children would have made such considerable progress. The researchers conclude that perhaps symbolic play is not something to be outgrown, but something to be encouraged and utilized to help develop representational thought structures.

Wertsch, McNamee, McLane, and Budwig (1980) conducted a study to explore how an adult and child dyad can function as a problem-solving system. Specifically, they studied the way mothers and their preschool children divided strategic responsibilities for problem-solving that involved making a puzzle in accordance with a model. The interaction of 18 mother-child dyads was video-taped and analyzed for verbal and nonverbal cues used by the adult to regulate the child's behavior. The child's gaze toward the model was used as a measure of how well the child was following an effective strategy. All utterances by the child and the adult were transcribed and coded to indicate the gazes toward the model and pointing toward the model, and the problem-solving that was taking place.

It was found that with an increase of age of the child there was a decrease in the proportion of eye gazes that were regulated by an adult. It was also found that when an older child looked at a model that child would be more likely to carry out the steps necessary to select and insert the piece correctly without adult assistance. The study supported the notion of transition from other, or adult, regulation, to self-regulation in connection with a crucial step. The researchers also stated that adult input may have been interpreted differently by children of different ages. Younger children did not interpret the adults' moves as being about strategic actions, whereas older ones did. The researchers stated that adult-child interaction is often structured. They recommended taking the social origins of cognitive processes into account as an important step to developing a more complete understanding of their form.

Palincsar, Brown, and Campione (1993) described a study to determine classroom dialogues that helped first grade students understand instructional passages within the classroom. The subjects consisted of six first grade teachers, each of whom worked with a group of six students. Five students in each group were identified as at-risk for academic difficulty. These children scored below the thirty-fifth percentile on the Stanford Early School Achievement Test, which is a standardized test of listening comprehension.

The study began with the administration of pretest measures to assess comprehension and the children's ability to recognize and use the principles presented in the instructional passages. The comprehension measure was administered by reading a passage to each child, and asking the child to respond to a series of questions. The questions measured recall and inference, as well as one question designed to test the child's understanding of the theme of the passage. Both the experimental and control children attained 47% correct scores on those comprehension assessments administered prior to the thematic dialogues. When examining those questions that assessed the ability to identify the theme of the passage, the experimental students were successful only 29.2% of the time, where the control was successful only 27.2% during the baseline test.

To assess children's ability to identify and use analogy underlying the various topics, and to determine how this ability changed over the course of the discussions, the children were presented a classification task in which they were asked to sort pictures that represented one of two themes. An example of one theme used was protection against enemies and adaptation/extinction. The children were asked to sort the pictures into two piles so that "the ones that go together are in the same pile." They were asked to talk aloud as they completed the task. When they were finished sorting, they were asked to again explain how they sorted the cards. The experimental and control groups were comparable in the way they sorted the cards, with the majority (43% and 37%, respectively) sorting based on physical characteristics.

Following the pretests both groups participated in three lessons designed to introduce them to the concept "similar" at the concrete and abstract levels. The experimental groups began discussions using the method of reciprocal teaching. Reciprocal teaching comprises guided practice in strategies for understanding text. It is based on Vygotskian perspective for learning to occur in social contexts. Reciprocal teaching helps the teacher and more capable students scaffold the learning of other students by (1) linking students' previous contributions to new knowledge in the texts, (2) requesting that students elaborate on their ideas, (3) helping maintain direction in the discussion, and (4) reworking students' contributions so they are integrated into the discussion. The teacher and students take turns leading the discussions, beginning with asking questions about the text content. The questions are followed with students summarizing what has been read, and then clarifying to restore meaning when a word or phrase is misunderstood or unfamiliar to the group. Finally, the group leader provided opportunities for predictions regarding upcoming content.

In this study, the reciprocal strategy was used to investigate not only students' learning from text, but also how to help students acquire and achieve ownership of new knowledge. The dialogues were used to learn simple science concepts related to animal survival themes, such as protection against enemies, and camouflage. The experimental group proceeded through the reciprocal teaching discussions each day, following listening to a passage about the concept. One passage was read to the children each day, for a total of 20 passages over the 20 consecutive days of instruction.

Students in the experimental group were able to recognize and use thematic information, as evidenced in a number of ways. They were able to generate questions asking how two things were alike, summarize including information across different texts, clarify the ways two things were different, and make numerous predictions that were predicated on information gained from previous texts.

Both experimental and control groups engaged in during and after intervention and posttest comprehension measures. During the first 10 days of instruction, the mean correct for the experimental group was 49.9%, and for the control group was 37.7%. The mean for the second 10 days was 70.0% for the experimental group, and 39.5% for the control group.

With regard to their ability to identify the theme of the passages after the first 10 days of dialogues, the experimental group children were correctly identifying the theme of the passage 45.5% of the time, and the control group was doing so only 14.9% of the time. The mean for the second half of the intervention for the experimental group was 63.9%, and the control group was 10.5%.

On the questions measuring children's identification of the analogy between the assessment passage and an instructional passage used during the dialogues, for the first 10 days, the experimental children attained a mean score of 53.1%, and the control children achieved 27.0%. For the second 10 days the experimental children achieved a mean of 76.6%, while the control children earned a mean of 17.3%.

A second measure was used to determine the children's ability to recognize and use analogies inherent in the instructional examples and novel examples was the classification task. The posttest classification task was administered by presenting the same pictures of the animals as during the intervention, one at a time. The children were asked to recall information about each subject. If the students mentioned the theme, this response was acknowledged. If the child failed to mention the theme, the interviewer mentioned it. Children were presented with new examples that they were asked to place in a pile while explaining their decision.

The results of the sorting tasks indicated that, whereas the children in the control condition sorted principally by physical characteristics, the children in the experimental groups made 54% of their sorting decisions based on thematic similarities. When sorting novel subjects, the experimental children used underlying principles they speculated these animals shared 20% more than did children in the control condition.

Although all children were exposed to the subjects covered in the texts, only those children who engaged in discussions of the texts began to view the subjects as problem paths, transferring knowledge from one situation to another. The control group children did not discover underlying themes on their own. Children in the experimental group developed a better ability to (1) understand text and identify themes of passages read, and (2) recognize and apply analogical information in the texts.

The researchers noted the evidence their study provided regarding two features of the lessons that served to facilitate student-teacher collaboration in the dialogues: the form of the discourse, and the nature of the texts. The form of the discourse within the experimental classrooms allowed students to assume a voice within their own classroom. They were able to take a role as discussion leader and were able to use the guidelines and strategies of reciprocal teaching to help them facilitate meaningful discussions. The strategies allowed the children to try out their ideas, and the strategies also represented tools to be used in a public manner, to solve the problems of understanding these texts and their themes.

The teachers also used support, or scaffolding, to maintain the children's engagement in the dialogues. Successful teachers used a variety of conversational techniques and opportunities to support the young children's discussions. Teachers were observed to use cued elicitations, paraphrasing of children's contributions, choral responses, framing of the children's responses, selective use of praise, and silence, to help students in navigating through the discussions.

The texts used in this study shared a common theme. Common themes allowed children to focus on analogies and to cross-reference texts. For instance, students spontaneously compared the hibernation of bears to ladybugs, though three months had separated the readings of both books. The researchers claimed that the extension of reciprocal teaching discussion to texts with recurrent themes gave rise to a shift from learning how to learn from text to learning how to use knowledge acquired from text. They further stated that because of the rich diversity of experiences and knowledge the children bring to the texts, the classroom of diverse learners become communities of knowledge users.

Feldman and Acredolo (1979) conducted a study with the purpose of testing the effect of self directed (active) versus other-directed (passive) exploration on the ability of children of two ages to master an unfamiliar spatial environment. A second purpose was to look for characteristics that differentiated between the accurate and inaccurate participants within each group. Specifically, the question was asked whether children who most readily generate accurate cognitive maps differ on other spatial or nonspatial dimensions from their less accurate age mates.

The subjects were 40 3- and 4-year olds from middle-class nursery schools, ranging in age from 3.25 years to 5.25 years, and 40 9- and 10-year olds from middle-class schools, ranging in age from 8.75 years to 11.17 years with a mean of 10.17 years. There were 20 males and 20 females at each grade level, and 20 children were tested in each of the four experimental conditions, divided so equal numbers of each age and sex were represented.

Memory for the location of an event was assessed in four experimental conditions that differed from one another in the type of exploration the child was allowed, active or passive, and in whether or not a landmark was present at the location to be remembered. The same unfamiliar hallway was used in all conditions.

In the two passive conditions the child accompanied an adult on a walk in search of a hidden object. Prior to the walk the child was shown a cup like the one he searched for. The adult held the child's right hand at all times to not block the object or other relevant cues on the child's left side from view.

Children in the active conditions also followed the path in search for the hidden cup. However, the adult followed behind the child, in no way leading the child through the hallway.

The time it took each child in the active conditions to find the object was recorded by stopwatch. For the children in the passive conditions the time was standardized. It was 45 seconds for the children who were led into a blind alley, and 35 seconds for those who were led directly to the hidden cup. The time was recorded for children in the active condition. Children in neither condition were allowed to engage in conversations.

For each child the distance between the actual location of the object and the location of the child chose was recorded. The data consisted of the distance error in feet for each child in retracing their steps back to the hiding place. There were no significant sex differences found at either age level, so an Age X Landmark X Condition analysis of variance was performed. The analysis revealed significant main effects of age with the 9- and 10-year olds performing more accurately than the 3- and 4-year olds $F(1, 72)=38.07$, $p < .01$, and condition, with subjects in the active condition performing more accurately than those in the passive, $F(1, 72) = 9.58$, $p < .01$. The interaction of Age X Condition was also significant, $F(1, 72) = 6.08$, $p < .05$, but the Landmark X Condition interaction was not, $F(1, 72) = 3.93$, $p < .10$. A Neuman-Keuls analysis of the Age X Condition interaction revealed that the active conditions had resulted in significantly greater accuracy than the passive conditions for the 3- and 4-year olds ($p < .01$) but not for the 9- and 10-year olds.

Younger children benefited more from being allowed to actively explore their environment. Older children were consistently more accurate than younger children, even when younger children were given the benefit of active exploration. The addition of a landmark did not significantly facilitate performance. Behaviors that involved the child in making decisions and choosing among alternatives were more likely than passive experiences to result in helping children acquire perceptual information necessary to complete a task successfully.

The data in this study clearly indicated that active exploration of an environment facilitates memory for spatial information in young children. From a practical point of view, it may be important for parents and teachers to know the benefits of active exploration in the child's knowledge of spatial layout. From an empirical point of view, it is important that researchers are aware that the mode of exploring space affect the performance of young children.

Miller, Brownell, and Zukier (1977) reported a study that examined the certainty of children as they made judgments on concrete-operational tasks. Sixty second graders and 36 fifth graders from a lower middle class participated in the study. There were equal numbers of boys and girls at each grade level.

The study used three methods of assessing certainty: a rating scale, a betting game, and a feedback phase in which the child responded to a disconfirmation of his or her answer. All students participated in two testing sessions, each lasting about 25 minutes. The average time between sessions was 16 days for the second graders and 15 days for the fifth graders. The purpose of each session was to assess the child's understanding of various concrete operations, and to measure the certainty with which the child held his or her responses. The five concepts assessed for all subjects were conservation of number, conservation of weight, conservation of length, transitivity of length, and transitivity of weight. The fifth graders were also assessed on their conservation of displaced volume.

The assessment in the first session involved the use of a 4-point rating scale. The scale was introduced as a way to tell the researcher how sure the student was of the answer. It was a horizontal line divided into four blocks, and from left to right each block indicated more certainty of response. The children were shown how to place an 'X' in a block to indicate certainty. The children were given high-certainty control tasks, such as how certain they were of their names, prior to being tested on the Piagetian problems to indicate their understanding of the procedure.

In session two, two measures of certainty were included. The first was a betting game. The child was shown a stack of 10 poker chips and two jars, one with the child's name and the other with the researcher's name. The object of the game was to finish with the most chips. Questions were asked of the child, and after the child answered he or she would choose to bet any number of chips from 0-10 that the answer were correct. If the answer were correct, all chips went into the jar; if incorrect, the experimenter got all the chips. Feedback was given on the control problem runs, but not on the Piagetian tasks. For the Piagetian tasks, the jars were placed behind a screen, blocking them from the child's view. Eight trials were conducted. Five of these trials consisted of Piagetian tasks.

The third measure of certainty involved a modification of the betting game. After being emptied, the jars were removed from behind the screen. The screen was removed revealing a special machine that the child was told indicated whether his or her answer was right or wrong. The child was told the light on the machine would go on for correct answers, and could then drop chips into the jar. The machine then provided disconfirming feedback to see just how certain the child was about the response. If the child resisted the feedback from the machine, the child was rated as more certain than the child who switched responses based on input from the machine.

There were no significant sex differences across tasks. There were significant differences on performance of Piagetian tasks as a function of age and concept. Chi-square tests revealed that the performance of fifth graders was superior to that of second graders on all concepts except conservation of weight, all X^2s (1) > 5.54, *ps* <.05. Analysis of interconcept differences using McNemar's test of change indicated the following differences: for the second graders, conservation of number was easier than all other concepts except transitivity of length, transitivity of length was easier than transitivity of weight and conservation of length, and conservation of weight was easier than conservation of length. For the fifth graders, conservation of number and transitivity of weight were easier than the conservations of length, weight, and volume, and transitivity of length was easier than conservation of volume (all X^2s (1) > 4.00, $p < .05$).

Children of both ages were able to use the rating scale and betting game to express different degrees of certainty. There were no age differences in use of the rating scale, but fifth graders were better at adjusting the size of their bets than were second graders.

Possible age differences in certainty were examined for each concept by means of Mann-Whitney *U* tests. Of the 10 possible comparisons (both ratings and bets for five concepts), only one reached significance: Fifth graders rated themselves more certain on conservation of number than did second graders ($z= 2.82$, $p < .01$).

The disconfirming feedback provided by the machine showed a significant effect of age on the conservation-of-weight trial. Of the 43 second-graders who gave conservation judgments on this trial, only 7 resisted the machine's verdict. Of the 29 fifth graders who gave conservation judgments, 11 resisted the machine ($p < .04$, Fisher's Exact Test).

The results showed that both the rating and betting measures yielded strong expressions of certainty by most children on most of the Piagetian problems. The expressions of certainty did not result from a simple response bias to claim confidence whatever the problem might be. When given the low- or medium-certainty control problems, most children in the sample were able to adjust their ratings or bets downward.

The strong certainty expressed by most subjects reduced the likelihood of finding differences in certainty as a function of age or concept. Age differences were rare. Concept differences were also infrequent, with most of the differences stemming from the strong certainty that was expressed for conservation of number.

Incorrect answers were given with much less confidence. The strongest difference to emerge from the rating and betting measures was the greater certainty for operational answers than for nonoperational ones.

The certainty that children express in their operational judgments depends on the method by which certainty is assessed. Assertions of certainty are common when the child is directly asked, challenges by the child when his or her answer is disconfirmed are much less common. Just as the level of apparent certainty may vary from one measure to another, so may the probability of finding differences in certainty among concepts or among children. Certainty cannot be satisfactorily studied through use of a single diagnostic device.

Discussion

Knowledge of child psychology is important for a researcher for two main reasons. First, it provides information to the researcher in terms of recognizing how children express their ideas. For instance, Wales, Colman, and Pattison (1983) showed that children can respond appropriately on naming tasks at levels beyond those expected by adults. Thus, a child could appropriately name scientific ideas beyond what most adults expect. However, simply naming an item does not indicate understanding. What is important to note is how the words are used in situations. If children express their ideas appropriately with in the context of a situation, it can be assumed they are showing their understandings (Nelson, 1986).

In addition, symbolic play can also allow children to express their ideas about the world, and help them develop more accurate conceptions. Golomb and Cornelius (1977) showed that symbolic play indicated students' understandings. When students were confronted with questions about their play, they were able to explain the meaning of what they were doing. When students are describing what is occurring during their play, and the meaning of the play, this can indicate their understanding of concept behind it. Nelson's (1986) idea of event knowledge is related to this idea of children explaining their play. The manner in which a child explains an event is representative of her understanding of the event. For instance, a child's description of a birthday party can give clues to the ideas the child holds about events that occur chronologically, and events that do not depend on order, but still occur at a birthday party. The manner in which a child explains her symbolic play is representative of her understanding of the meaning of her pretending. If a researcher attends to student explanations of events or play in the classroom concerning concepts being learned, the researcher can interpret those explanations as being representative of the ideas the child holds about the concept.

Second, the literature also points to signs researchers can look for when seeing whether teachers are responding to student ideas. Feldman and Acredolo (1977) have shown that children, particularly young children, make more sense of their environment when they are actively involved than when they are passively being led. Teachers who are providing activities for primary students are likely being more sensitive to their developmental levels than teachers who are providing textbook readings for students. Children can be certain of their ideas, yet will change them in face of disconfirming evidence (Miller, Brown, & Zukier, 1977). Thus, the activities teachers choose for students are important to note. If the activities cause students to confront their ideas, then the teacher is responding to those ideas. If the activities seem to be to simply allow students to interact with materials, then it is unlikely the teacher is responding to student ideas. If teachers encourage children to share ideas, children become better at sharing, and more willing to listen to others. Their willingness to share and modify ideas leads to more meaningful learning (Palinscar, Brown, & Campione, 1993). Thus, teacher who are encouraging students to share ideas are more likely to respond to those ideas in their teaching. The remaining question is what primary teachers will do when they respond to their students' ideas, and the effect on their students.

Conclusions and Recommendations

From the research on children's ideas in science, it is apparent that children of all ages have many stable and useable ideas about the world. Since students of all ages bring their own ideas to the classroom, it is necessary for all teachers to have an awareness of these ideas. An awareness of children's ideas enables teachers to deliver lessons to scaffold toward more accurate conceptions. It seems conventional instruction in science has not been satisfactory for changing student ideas.

Research on the learning cycle builds on Piagetian theories of developmental psychology. The learning cycle purports to build on students' initial ideas and then cause disequilibration when students confront those ideas, forcing a change in understanding. It was not the original intent (Karplus & Thier, 1967) of each science lesson to contain all "phases" of the learning cycle. The intent was to describe three types of lessons necessary for students to develop appropriate conceptions. However, it was sometimes unclear whether the teachers were aware of the ideas the students held while using the learning cycle as a manner of instruction (Smith, 1983). Thus, it is questionable how effective a teacher can be at changing ideas using the learning cycle in such a fashion. Teachers also may find use of the learning cycle, or a generative learning model more difficult than a traditional model, particularly in planning objectives (Flick, 1996). However, Zahorik (1970) noted that teachers with less stringent plans were more attentive to student ideas. Perhaps teachers who plan to account for these ideas would more effectively use them in instruction.

From the review of conceptual change studies it seems, in general, these studies have not allowed the teacher to be the one assessing and planning to address student ideas in classroom practice. In each case it was the researcher who sought out the student ideas, and sometimes the teachers were unaware of the ideas the researcher uncovered (Erlwanger, 1975; Joshua & Dupin, 1987; Stavy, 1991). When the teacher was made aware of children's ideas and conceptual change literature, the teacher may seek to plan lessons to address these ideas (Flick, 1995). Teachers who are unaware of their students' misconceptions can certainly not seek to change them (Erlwanger, 1975; Smith & Anderson, 1984), yet they do not have the time in their days to clinically interview each student. Because we cannot define every concept in a classroom is not to say we need a study for every concept at every level in every discipline that defines typical misconceptions, but we need a study of effective teaching practices to see how teachers identify their own students' conceptions, plan and carry out instruction seeking to change these, and assess change in student conceptions. To describe effective teaching practices that can be used in a classroom setting, it is necessary to research classrooms to see how classroom teachers, in the absence of time to conduct clinical interviews, uncover their students' individual conceptions. In addition, it is be desirable to see how these practicing teachers use their students' ideas to plan and teach science toward conceptual change.

From the review of literature on teachers' thinking it is apparent there are many competing factors to consider when teaching. Competing factors are important to note when studying a single influence, such as children's ideas. Children's ideas are just one influence on teaching practice. If it appears teachers are not taking into account children's ideas it is important to note other factors that may be constraining the teacher's ability to act on student ideas.

It is also apparent from teachers' thinking literature that though teachers are capable and likely to take into account their students' thinking (Berliner, 1987, Bromme, 1987), it is equally unlikely they would be able to describe how they are able to do so if asked (Berliner, 1987). It is important to use classroom observation when identifying what teachers actually do in their classroom and how they respond to what influences them.

Teacher's thinking studies also point out that teacher beliefs influence their instruction (Clark & Yinger, 1987). If teachers believe in the importance of knowing student ideas it is likely they will try to take them into account when teaching. To understand teacher beliefs a discussion or interview with the teacher would be appropriate in conjunction with classroom observations to note how the beliefs are manifested and whether they are corroborated in practice. The current study will use classroom observations as a major source of data.

Though studies of teacher content knowledge showed science subject matter knowledge is weak for primary teachers (Kruger, Palacio, & Summers, 1992; Kruger & Summers, 1989; Lawrenz, 1986), it is also apparent that primary teachers are capable of learning science content and teaching conceptually (Neale, Smith, & Johnson, 1990; Smith, & Neale, 1989; Stoddart, Connell, Stofflett, & Peck, 1993). It is important to believe that because primary teachers are able to understand science concepts with sufficient depth to be able to teach science to young children. Primary teachers are also fortunate in having their students all periods of the day. They have the advantage of being able to spend much time with their students, enabling the teachers to have a deeper knowledge of their students.

Background in child psychology supports students learning experientially and at their own developmental levels (Feldman & Acredolo, 1979). Teachers who are enabling students to be actively involved in their learning are being more sensitive to their developmental levels and more open to student ideas.

It is also apparent that students can attain higher levels of understanding when scaffolded by a more knowledgeable person (Golomb & Cornelius, 1977; Palincsar, et al, 1993; Wertsch, et al, 1980). Students can also come to a better understanding when forced to confront their thinking about a topic (Miller, et al, 1977). Teachers who are providing activities to encourage students to confront their own ideas are responding to student ideas in their teaching. Even if the students are developmentally unable to reflect on their own knowledge, they can still develop understandings (Vygotsky, 1986). Since young children are busily making sense of their world, and do so with or without the help of adults, effective science instruction should begin very early so they have a better chance of developing appropriate conceptions, and positive attitudes toward science. It is not the intent that young children will come to full scientific understanding of a concept, but are capable of developing conceptions toward that understanding.

Chapter III

Design and Method

Introduction

Though it has been stated that students come to the classroom with their own ideas concerning the natural world (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyburg, 1985), a review of the literature on conceptual change calls into question whether the teacher and researcher are aware of the same conceptions students hold. Often a researcher prescribes a teaching strategy for the teacher to use to change the misconception, yet it is not known whether the teacher is aware of the misconceptions held by the students. In addition, the researcher tends to use individual interviews to uncover student ideas, a method that is impossible for a classroom teacher to use. There are also doubts whether the strategies advocated by the researcher are implemented as intended due to the lack of classroom observation in the studies.

The learning cycle purports to promote change in students' conceptions. However, some studies including the use of the learning cycle do not include a portion of the lesson during which students share their original ideas about the science content (Smith, 1983). It is difficult to see how teaching can build on and change ideas when it is not clear whether the original ideas are known by the teacher.

A review of the literature revealed few studies concerning the science learning of primary students. Since children of primary age are in the process of forming their ideas of the world and how it works and are developing attitudes toward school and science, it is important to provide effective science instruction for these students. The current study focused on how knowledge of student ideas affects teaching strategies. Research into how experienced primary teachers approach science teaching that accounts for students' ideas will provide direction for professional development. In addition, understanding how classroom teachers can effectively address student ideas provides insight in developing better primary science teaching strategies.

The observations in this study focused on describing (1) students' personal expression of their own ideas in class, (2) teacher recognition and interpretation of student ideas, (3) teacher responses to those ideas, and (4) the possible relationship of teacher actions to student knowledge. To gain an understanding of these areas it was necessary to conduct an in-depth study of teaching practice. Thus, a variety of data sources were used. These sources included video- and audio-taped pre- and post-instruction interviews of the teachers and students. The interviews of the teachers provided insight into their views of science teaching and knowledge of content and student ideas. The post-instruction interviews gave information concerning teacher perception of their own instruction, teacher understanding of student knowledge, and how their teaching was affected by student ideas. From one video-taped lesson a stimulated recall interview was conducted of the teachers reflecting on their teaching. The stimulated recall interview provided specific data linking teacher thinking and classroom practice. The pre- and post-instruction interviews of students provided information on student content knowledge as well as student perceptions of teacher practice.

Classroom observations were an important source of data. Previous research on conceptual change science teaching has been weak in this area. To verify that teachers delivered instruction claimed in interviews, and to note when teachers were attending to student ideas, it was necessary to directly observe and video-tape classroom teaching. Videotapes of teaching episodes allowed the researcher to review and focus on specific lessons. In addition, documents such as lesson plans and student work were collected to help confirm teaching foci. Few explicit lesson plans were actually written by the teachers, however.

Subjects

Sixty-one primary (K-2) teachers in a middle class school district in western Oregon were contacted by telephone to request participation in the study. Of the 61 contacted, 18 primary teachers responded to the request to participate. Ten of those who responded agreed to participate. The researcher endeavored to find a minimum of three teachers who met certain criteria. The criteria included teachers (1) delivering the same science content during the course of the study, (2) focusing on student learning as evidenced by a minimum of five years experience, (3) teaching science as a separate subject, and (4) having adequate content knowledge for instructing the students in the topic being taught. Because of the difficulty of finding teachers who shared the criteria, the fourth criterion was dropped. Dropping the fourth criterion resulted in the selection of teachers who demonstrated a range of knowledge about the subject matter.

The number found to share the characteristics required by the study determined the number of teachers selected. From those who agreed to participate, two second grade teachers were found who met the selection criteria. The teachers each taught a unit of astronomy during the spring quarter at their school, satisfied the criterion that they teach a common content area. The participating teachers had 24 and 10 years of teaching experience, mostly in the primary grades, satisfying the criterion that they could focus on student learning. They were no longer focused on new teacher concerns, such as classroom management and establishing routines. The teachers had sufficient experience and expertise to allow them to collaborate on a published book of primary mathematics activities. They were also active in presenting mathematics workshops for teachers. Additionally, they wrote, and received, a $5,000 grant to further develop mathematics programs for primary children. This grant money was used to deliver teacher inservice programs and to produce units for second grade students.

The teachers satisfied the third criterion by teaching science as a separate, but integrated subject, almost on a daily basis, while they were delivering science units. Average lengths of lessons during the astronomy unit ranged from one-half to an hour-and-a-half daily. In addition to separate time devoted strictly to astronomy concepts, the teachers connected art, math, and language arts activities to their unit. The teachers identified what they were teaching as science.

Both taught thematically, cycling science concepts with language arts and social studies concepts, throughout the school year. The units as cycled through the year, were about 8 weeks long. The astronomy unit lasted 9 weeks for Teacher One, and 8 weeks for Teacher Two. During the term of instruction in the astronomy unit Teacher Two had an intern teacher who taught 12 astronomy lessons. The intern teacher played an integral part in delivering instruction. She had taken a college-level astronomy course while earning her teaching degree. She agreed to participate fully in the study. She participated in pre- and post-instruction, and video stimulated recall interviews, and allowed her lessons to be videotaped.

The area of astronomy was selected because both second grade teachers were presenting a unit on astronomy to their students in the spring term. It was not the researcher's intent to influence the curriculum, but to observe the natural occurrences. In the primary grades a unit on astronomy generally includes students creating models, watching the day and night sky, and making observations. Due to the abstract nature of astronomy, and the fact that it is not possible to manipulate and observe the planets, there is limited opportunity for hands-on experience. However, this science concept is a topic commonly found in the primary grades and fits nicely with the *Benchmarks'* (1993) recommendation that primary students know ideas about the earth, moon, and sun, the stars, and patterns of movement in the sky. Both teachers were able to include hands-on activities to use to represent movements of the planets, sun, and moon, in the sky.

The teachers' students were also included in the study. Each teacher identified 10 of their 20 students to participate in interviews. The students interviewed represented a balance of gender. Though the sampling of students was stratified with respect to gender, this study did not analyze differences that teachers may have had in eliciting and addressing student ideas depending on student gender. There could be differences in how the teachers responded to children's ideas based on the gender of the students expressing those ideas. While it was intended that a range of student abilities in science be represented, obtaining the range proved to be a difficulty. Teacher One provided a list of 10 students, five girls and five boys, but did not believe it was developmentally appropriate to label second graders as high, medium, and low achievers. Instead, she said she identified the students according to the amount of individual adult attention they already received. If students received much adult attention already, they were not selected to participate in the interviews. Selecting students who already received much adult help could mean students who received special support services to help them attain higher levels of reading or mathematics were not selected. It is possible that higher achievers who did not receive individual adult attention via support services were selected by the teacher to participate in this study.

Teacher Two selected 10 students to participate in interviews according to gender and achievement levels in science. Teacher Two saw no problems with identifying her students by achievement levels. She told the researcher that she would be surprised if the researcher's assessment did not agree. Because of the difficulty in knowing how Teacher One viewed the students in terms of achievement, there was no analysis to separate how teachers may have differentially elicited and addressed student ideas based on perceived achievement.

The Human Subjects Review Board reviewed the study. A letter describing the general intent of the study, the types of data to be collected, and the time commitments involved was given to all participants (see Appendix A). Teachers, students, and parents of students provided written permission to participate in the study. A response letter confirmed the participants' willingness to serve in the study, affirm confidentiality of data, and was used as an informed consent form. Approval was obtained from the Human Subjects Review Board to conduct the study. In addition, district approval for conducting the research was obtained through the District School Board.

Data Sources

There were four phases of data collection within this study. The first phase described student expression of ideas, the second noted teacher recognition of student ideas, the third described the responses teachers made to student ideas, and the fourth noted effects on student content knowledge. A variety of data sources were used to provide evidence for these phases. The data were collected over a three-month period in the spring of 1997. Table 1 identifies the areas of interest to the researcher, and the data sources used to describe those areas.

Pre-Instruction Interviews

All interview protocol questions were presented to a panel of five experts for validation. The panel of experts consisted of university science educators as well as university science faculty. The panel of experts participated in validating content knowledge and all other interview protocols. Some points raised were those of keeping numbers of questions equal for each teacher, eliminating redundant questions, and maintaining consistent wording of the interview questions. Following negotiation of these points, all experts approved of all interview protocols.

The teachers were interviewed prior to presenting instruction on their astronomy units. The purpose of the interview was to obtain information about the teachers' beliefs toward teaching science, methods for science teaching, knowledge of student ideas in astronomy, and content knowledge of the science concept. An interview was used in which the subjects were allowed to speak freely about their own points of view. These interviews were semi-structured to focus on key questions, but open-ended to allow the

Table 1

Planning Matrix for Phases of Data Collection

Data Collection Phase	Why is it Necessary to Know This?	What Kind of Data Will Answer the Question?	What is the source of Data?	Timelines for Acquisition
1. Student idea expression	To see whether students express ideas in the classroom	Student/teacher interaction Student interview responses.	Classroom observations Pre-instruction interviews	spring term 1997 early spring term
2. Recognition of student ideas	To see whether teachers recognize student ideas	Teacher interview responses Student/teacher interactions	Pre and post interviews Classroom observations	spring term throughout spring term
3. Response to student ideas	To see whether teachers respond to student ideas	Classroom activities. Student/teacher interactions Teacher response to interview concerning teaching	Classroom observations Stimulated recall interview responses	throughout spring term middle of spring term
4. Effects on student knowledge from teacher actions	To see whether teacher response effects student learning	Student work, interview response Teacher interview response	Student/teacher post interviews Collection of student work	late spring term throughout spring term

teachers to respond to what was important to them in their teaching of astronomy in second grade.

Teachers felt uncomfortable with being video-taped, so interviews of teachers were audio-taped only. The 45-minute interviews were audio-taped and transcribed. Teachers were individually interviewed in their own classrooms after students were released for the day. The interview protocols were developed to focus on teacher thoughts that would help the researcher interpret teacher content knowledge and views of student ideas. The following interview protocol was used in the pre-instruction interview with the teachers:

Teacher Background:

1. How long have you taught, and what grade levels? Which grade level is your favorite to teach and why?
2. What topic do you like teaching the best? Why? What topic do you like teaching the least? Why?
3. Describe a typical teaching day.

Teacher Goals and Planning:

1. What are your goals for science teaching? What do you want students to know at the end of a science lesson? At the end of a unit? At the end of the school year?
2. How do you plan to teach science? What do you think about when planning to teach science?
3. How long do your science units last? When do you teach science? How often do you teach science?
4. What is the most important factor you consider when planning a science lesson? When teaching a science lesson?
5. What is the role of science in the primary classroom?
6. How do you think science should be taught? How do you teach science?

Views of Student Understandings:

7. How do you know what children understand about concepts you are teaching? How do you structure your classroom? How do children work on projects (groups, individual)?
8. What is the most effective way for you to know your students' understandings about the science they are learning?
9. Do you use students' thinking and ideas when teaching science? How?

Teacher content knowledge about the concepts of astronomy they intended to teach to the students was also assessed. The content knowledge interviews took place approximately one week after the previous interviews. The content knowledge interviews were about 30 minutes in length and were audiotaped and transcribed. Teachers were individually interviewed in their own classrooms after students were released for the day. Teachers used in explaining their own ideas. The props included a variety of sizes of balls, and paper and pencils for teachers to diagram their conceptions. In the act of discussing their ideas, the teachers thought about the meanings they were making of astronomy they may not have otherwise done if not interviewed. Having teachers think about their ideas undoubtedly influenced the study, but was a necessary step in understanding their ideas. Teachers were determined to have adequate content knowledge by their responses to the interview protocol. It was determined that Teacher One's level of content knowledge was higher than that of Teacher Two. Teacher One was able to give accurate responses to all questions and to provide further in-depth explanation than was required by the protocols. Teacher Two was unsure of her responses and unable to fully develop responses to all questions. Her responses often were phrased in terms of what could be taught to second graders rather than a description of her own knowledge. When refocused to discuss her knowledge she did so but was often unsure of her own responses. The Intern Teacher was present at the pre-instruction interview of Teacher Two and was later interviewed. Thus, her responses were likely influenced by her presence at Teacher Two's interview.

The following interview protocol was used to guide the discussion to discern the teachers' content knowledge of astronomy. The questions concerning the content area were developed from the *Benchmarks'* recommendations for what children should know after second grade, and based on objectives teachers gave for what they wanted students to know at the end of the unit.

Teacher's Knowledge of Students' Preconceptions of Astronomy:

1. How many times have you taught this unit?
2. Tell me what you want the students to learn from this unit.
3. What are key ideas and concepts you want students to learn? Why do you think these topics are important things for children to learn? Why did you choose these topics?
4. How will you know if students have met your objectives?
5. What are typical ideas children have about the key ideas and concepts you want to teach them about astronomy before instruction?
6. How do these ideas influence their learning?
7. Do children's conceptions influence teaching? What makes it difficult to address children's ideas in science? (Ask these questions only after the others, and if teachers do not bring up the topic on their own.)

Concepts that Relate to Astronomy:

Teacher Goals:

1. What is astronomy? What kinds of things do you think are important to know about astronomy?

2. What kinds of astronomy-related jobs do you want students to know about at the end of the unit?

3. Can you tell me the names of the planets? Which do you think is the largest? The smallest? Which is the hottest? The coldest?

4. Can you draw me a picture of how the planets are in the sky? (Provide paper, pencils, crayons.) Can you put the sun in your picture? Where would it go in relation to the planets you have drawn? (Probe for names of planets the student has drawn.)

Benchmarks Goals:

5. (Provide a new sheet of paper.) What shape is the earth? Can you please draw a picture of the earth? On your drawing, please point to where you stand on the earth. (Using the child's drawing.) What if you dropped a ball—which way would it fall?

6. What kinds of things do you see in the sky during the day? (Do you ever see the moon in the sky during the day? When?) What kinds of things do you see in the sky at night? (Do you ever see the sun in the sky at night?)

7. (Provide a variety of sizes of balls.) Please choose one of these balls to be the sun, one to be the earth, and one to be the moon. Does the sun, earth, and moon move in space? Can you show me how they move using the balls? (Provide a new sheet of paper.) Can you please draw a picture of how you think they move in space?

8. Does the moon always look the same in the sky? Why does it sometimes look different? What different shapes have you seen? Can you please draw some of those shapes? How often does the moon change shapes?

9. Tell me what you know about stars. How many stars are there? What colors can they be? What are stars? How bright are they? Are they all the same brightness? Why or why not?

10. Is there anything else you want to tell me about astronomy?

Following the pre-instruction interview of the teachers, the selected students were interviewed to assess their knowledge of astronomy. The protocol for students was similar to the teacher protocol, but the focus was on the students' ideas. Each student was individually interviewed while being video- and audio- taped. The interviewer took care not to lead the students to "correct answers" but allowed students to respond with their own ideas and thinking (Piaget, 1929). Questions were open-ended and all responses accepted. Some ideas were probed and even challenged by further problems posed by the interviewer. Students were encouraged to elaborate on their ideas through their responses to questions and problems. Probing questions followed the initial questions to allow students to elaborate on their ideas. In addition, props were available at all interviews to help students describe their ideas and thinking. The props included a variety of sizes of balls, and paper, pencils and crayons for students to diagram and record their ideas. The following protocol was used to guide the student interviews.

<u>Students' Views of Astronomy</u>

<u>Teacher Goals:</u>

1. Your teacher has told me and has talked to you about studying astronomy. What is astronomy? What kinds of things do you think you will be learning about?

2. When you grow up, what kinds of jobs might you have if you studied astronomy?

3. Can you tell me the names of the planets? Which do you think is the largest? The smallest? Which is the hottest? The coldest?

4. Can you draw me a picture of how the planets are in the sky? (Provide paper, pencils, crayons.) Can you put the sun in your picture? Where would it go in relation to the planets you have drawn? (Probe for names of planets the student has drawn.)

Benchmarks Goals:

5. Provide a new sheet of paper.) What shape is the earth? Can you please draw a picture of the earth? On your drawing, please point to where you stand on the earth. (Using the child's drawing) What if you dropped a ball—which way would it fall?

6. What kinds of things do you see in the sky during the day? (Do you ever see the moon in the sky during the day? When?) What kinds of things do you see in the sky at night? (Do you ever see the sun in the sky at night?)

7. (Provide a variety of sizes of balls) Please choose one of these balls to be the sun, one to be the earth, and one to be the moon. Does the sun, earth, and moon move in space? Can you show me how they move using the balls? (Provide a new sheet of paper) Can you please draw a picture of how you think they move in space?

8. Does the moon always look the same in the sky? Why does it sometimes look different? What different shapes have you seen? Can you please draw some of those shapes? How often does the moon change shapes?

9. Tell me what you know about stars. How many stars are there? What colors can they be? What are stars? How bright are they? Are they all the same brightness? Why or why not?

10. Is there anything else you want to tell me about astronomy?

Student interviews took place in a secluded workroom area between both classrooms. Students were individually interviewed. Students from Teacher One's class were interviewed first because she began her unit earlier than Teacher Two did. Interviews lasted approximately 30 minutes per student. Interviews took place during the school day with individual students being pulled aside during the course of the day. Student interviews provided information about what students in this classroom understood about astronomy, and allowed the researcher to identify when students expressed those ideas in the class. The researcher compared statements students made in class with those they made during interviews. The comparison enabled the researcher to note whether any of the ideas the students have expressed in the interviews were made public in the classroom, and under what circumstances this was so.

Classroom Observations

Classroom observations were the primary data source and carried the greatest weight in data analysis. They were used to decide any discrepancy in the data, deemed the most reliable source because they were a picture of what actually occurred in the classroom, not what the teachers reported they did in their classrooms. Classroom observations were conducted to allow the researcher to note the general process of science instruction in each particular class, using the knowledge gained from interviews. Classroom observations allowed the researcher to note (1) whether and when students expressed ideas, (2) whether and when the teacher recognized student ideas, and (3) whether and how the teacher responded to those ideas. Classroom observations were important because they gave information not obtainable solely through interviews. Classroom observations took place during virtually every science lesson of the unit in both classrooms. Though subjects are often integrated in the elementary schools, observations only took place during the science period of the day. If the teachers did not address student ideas during science it is unlikely they did so during other periods. In connection with classroom observation, lesson plans and student work were collected. Collection of these plans allowed the researcher to note the match, or mismatch, between what was planned for instruction and what actually took place. It is possible the teacher would plan to collect student feedback, yet be unable to do so for some reason. Collecting the plans, in addition to observing the lesson, allowed the researcher to note what occurred that prevented the teacher from eliciting student ideas as planned, and why. It was, however, eye-opening to note that neither Teacher One nor Teacher Two used detailed lesson plans. The Intern Teacher however, did.

Observations took into account all activity in the classroom, but focused on three areas (1) student expression of ideas, (2) teacher recognition of student ideas, and (3) if and how the teacher responded to those ideas. When observing in the classroom, attention to student expression of ideas involved noting whether students were stating ideas they believed about the science content and meanings they were making from their activities. If the student described beliefs about the science content, it was noted that students were expressing ideas, and what students actually stated was recorded. These ideas expressed in class were compared to those given in pre-instruction interviews to see whether all ideas became known in the classroom.

To note whether the teacher recognized student ideas, teacher-student interaction provided an important key. Based on previous research teachers acknowledged student input in several ways. If the teacher responded to a student's idea with (1) a re-statement of the idea, (2) a probing question for more information about the thought, (3) a look that indicates acknowledgment of the idea, or (4) a response, verbal or otherwise, indicating the idea was heard but seems unbelievable, a note was made that the teacher recognized the student's idea. Points three and four were high inference data, yet were behaviors that were easily noted by the researcher, thus were included. The researcher questioned the teachers regarding their behaviors, when behaviors such as points three and four were noted in the classroom.

The researcher noted large and small group interactions, as well as individual student/teacher dyads, during which the teacher was addressing student ideas. Teacher acknowledgment of student ideas without taking them into account was also noted.

During classroom observations the researcher remained as unobtrusive as possible. The researcher arrived prior to the science lesson and left well after the lessons were concluded. The teachers introduced the researcher to their classrooms as someone who was interested in science and then proceeded with the unit. The researcher observed in each classroom for several lessons prior to the beginning of the astronomy unit. Prior to data collection the researcher saw science lessons in Teacher One's classroom and mathematics lessons in Teacher Two's classroom. The researcher began by sitting in a location out of the way of classroom activity. It did not take long for the students to become accustomed to the researcher in the classroom. There was always a variety of adults in each classroom, from parent helpers to intern and practicum teachers. The researcher was simply another adult in the classroom. The researcher moved about the room and watched and listened to small group interactions prior to official data collection.

Observations took place for each science lesson. Each lesson was videotaped. The video camera was placed in a location away from classroom activity to remain unobtrusive. The students quickly became accustomed to the video camera as evidenced by their lack of concern whether it was focused on them or not. Because of the importance of hearing teacher-student interactions, the teacher wore a microphone that picked up the teacher's voice and any student talking nearby. The camera's microphone was used in large group discussions, and the remote microphone was plugged in when the teacher was engaging individual students in discussion. It was not necessary to move the camera in either class. The zoom feature was used on the camera to provide close-ups on the student and teacher as they engaged in dyad interaction.

Following recording of the science lessons the researcher transcribed each videotape. All teacher-student interactions were transcribed, and a narrative description was made of each activity. While reviewing the videotaped lessons the researcher made comments regarding what occurred in the classroom and identified those as 'observer comments' (O.C.). The focus of the notes was on classroom activities, time for each activity, the researcher's perception of the teacher's purpose for each activity, or lesson segment, any expression of student ideas, and any indication of the teacher's recognition or response to those ideas. Any reflections or interpretations made by the researcher were noted in a researcher log of observations included with each day's transcription. Any discussion between teacher and researcher was also recorded and included in the data set. Transcription of each lesson took place at the nearest convenient time to the lesson, generally the evening following the lesson. Quick transcription allowed the researcher to remember the activity more clearly enabling her to record impressions and note them in the transcriptions.

The following is an example of how classroom observation data were interpreted. During an activity on orbits a child, Billy, stated, "Mars goes all the way around the sun. It goes close and then far away." The teacher recognized that Billy was expressing an inaccurate idea. She asked Billy to elaborate with, "What makes you think it goes closer and then farther away?" Billy stated, "Because gravity is more stronger on one side." The teacher immediately held a class discussion about gravity:

> Teacher: Are people on the South Pole upside down or falling off the Earth?
> Students: They don't fall off because of gravity!
> Teacher: Do you think gravity is the same at the North and South Poles?
> Students: (disagree) Yes, No.
> Teacher: What would happen if it weren't the same? What if there were more gravity at the North than South Poles?
> Students: People might fall off.
> Teacher: I have never been to the sun, have you?
> Students: No!
> Teacher: My guess is because the Earth is round and a sphere, and spinning, and because the sun is also round, that the gravity is probably what?
> Students: Equal.
> Teacher: Otherwise if the gravity on Earth was not equal, some places you would weigh more than others. Okay. If the gravity on the sun is pretty equal all around, how do you think the path of the planet would be?
> Student A: Equal.
> Teacher: Show me. (Student 1 moves her planet an equal distance around the sun) Okay—Student 2 can you show me what you think it does around the sun?
> Student B: (Moves the planet close to the sun on one side, and far away on the other side). It is closer to the sun on one side because how would you have winter, spring, fall?

Teacher: Oh—so you heard that in different seasons planets are closer or farther away from the sun. Seasons are something we will have to study. You still think it might be closer to the sun when it moves around that way. If the reason is not the unequal gravity can you think of another reason?
Student B: No.

The teacher recognized Student B's idea as evidenced by the probing question. The teacher used that information to hold a discussion about gravity during which she hoped Student 2 confronted the idea sufficiently to change it. Student B's expression of the idea likely influenced teaching practice in this instance. It is evident that Student B's description of the orbit influenced the teacher to hold the discussion about gravity. However, the effectiveness of the discussion was questionable. The teacher was asked whether she planned to discuss gravity at that time, and she stated she did not plan to discuss it, but when Student 2 stated his theory she decided to address it. The teacher did not plan the discussion and so did not appear to have thought about how to represent an idea of gravity in a manner that would be more accessible to young children. She stated that she often changed the direction of her lessons from student input. When Student B clung to his idea about the unequal orbiting of the planets around the sun following the discussion, the teacher later planned to deliver a lesson about seasons to help him, and other students, have a better understanding of the Earth and sun in producing different seasons. However, the lesson was not presented given the school year ended. Thus, holding the discussion about gravity was coded "immediate response to student ideas," and the planning of the lesson on seasons was coded "planned delayed response to expressed student idea."

Mid-instruction Video Stimulated Recall Interview

Further data regarding teacher response to student ideas were collected at a mid-instruction, stimulated recall interview designed after the video-stimulated recall format described in Calderhead (1981). The researcher viewed the videotaped sessions of classroom instruction and chose a lesson delivered by each teacher and the intern teacher, during which it was determined students expressed ideas, either voluntarily or from elicitation. The researcher selected stopping points at which (1) students expressed ideas, (2) the teacher recognized student ideas, and (3) the teacher responded to student ideas. The teachers also had the opportunity to select stopping points. Teachers were instructed that the tape could be stopped at any time the teacher wished to discuss the lesson. The teachers seemed to be comfortable viewing their own teaching. Teacher Two mentioned she would enjoy watching her teaching because it had been a long time since she had viewed, and thought about, her teaching. Each teacher did choose to stop the video at points other than those pre-selected by the researcher. An advantage of using stimulated recall is that teachers have their own teaching on videotape to prompt thinking rather than relying solely on memory. Calderhead (1981) further stated that recall of events is considerably greater in the stimulated recall context. Since it was desirable for this study to have the teachers recall events and their thought processes in adjusting their teaching in response to those classroom events, stimulated recall provided an appropriate method. Teacher One stated that had she not seen the videotape as the interview questions were asked, she would not have been able to remember exactly what had happened, stating "there have been a lot of lessons in a lot of subjects since then." The disadvantages of stimulated recall include the fact that the teacher may not provide the researcher with the teacher's actual thoughts at the time of teaching. Calderhead (1981) mentioned that teachers may distort recalled thoughts in order to present themselves in a more favorable light. It could be that information is not available in verbal form, and must be reconstructed by the teacher, which could lead to a distorted representation of the teachers' thought processes (Ericsson, & Simon, 1980). Comparison of classroom observation to interview data helped the researcher mediate any discrepancies.

Individual protocols were developed for each teacher, including the intern teacher. The same number of questions was included in each protocol, and an attempt made to keep the wording as similar as possible. However, since each lesson was a different topic, the questions were altered for each teacher. Questions were written that focued on the teachers' perceptions of student ideas in the classroom, and how the teachers recognized and whether they responded to the ideas. The teachers were encouraged to stop the video tape at segments that were meaningful for them to gain insight into what they believed was an important focus in the classroom instruction. The names contained within the protocol are pseudonyms. Questions for the stimulated recall interview protocols follow.

Teacher One—Video-Stimulated Recall (VSR) Interview Protocol

Setting the scene

We are going to be watching a videotape of your orbit lesson from your astronomy unit. I have some questions to ask you about your teaching, and have some stopping points selected at which to ask those questions. You should also feel free to stop the videotape at any time and discuss your teaching or thoughts about what was happening, especially at points where you were making instructional decisions.

1. What were your goals for this lesson? Given that astronomy, and planetary orbits are an abstract concept difficult to understand, what do you expect students to understand about orbits? What do you expect them to understand about the orbits about Neptune and Pluto? How do you attempt to make these concepts accessible to children?

2. In what ways did you expect students to respond to your prompt? What did you think students already knew about planetary orbits? What did you think they did not know about planetary orbits?

3. Stopping Point One: When Mark and Frank were pretending to be Pluto and Neptune, what did you think when Mark said, "I think Neptune and Pluto change places because Neptune's orbit is an oval?" How did you decide your response? What do you think they understand now?

4. Stopping Point Two: When Judy was moving her planet around the sun, what did you think? (She was moving it around the top of the sun, in circular motion.)Why did you decide to have her stand and move the planet? What do you think she understands now?

5. Stopping Point Three: When Larry was talking about the planets moving closer to the sun on one side than the other, what were you thinking? How did you decide your response? What do you think Larry knows about planets now?

6. Stopping Point Four: When students were stating that people would not fall off Earth because of "gravity," what do you think they meant by that? How did you decide your response? What do you think they understand about gravity now?

7. Stopping Point Five: When Norm still believed the planets move closer to the sun on one side than the other because it explains seasons, what did you think? How did you decide to respond? What do you think he understands now?

8. Stopping Point Six: The children in your class had many different explanations for why Pluto and Neptune are sometimes closer than one another to the sun. What did you think of their explanations? How did you decide to respond? What do you think they understand about Pluto and Neptune's orbits now?

9. Have (Will) you used (use) any of the student ideas in your lessons? How?

10. Is there anything else you would like to tell me about the lesson?

Teacher Two—VSR Interview Protocol

Setting the Scene

We are going to be watching a videotape of your first lesson in your astronomy unit. I have some questions to ask you about your teaching, and have some stopping points selected at which to ask those questions. You should also feel free to stop the videotape at any time and discuss your teaching or thoughts about what was happening, especially at points where you were making instructional decisions.

1. What were your goals for this lesson? Given that astronomy is an abstract concept difficult to understand, what do you expect students to understand? How do you attempt to make these concepts accessible to children?

2. In what ways did you expect students to respond to your prompt? What did you think they already knew about astronomy? What did you think they didn't know?

3. Stopping Point One: When Karen said "People think Uranus was knocked over on its side" what did you think? How did you decide your response? What do you think she understands about Uranus now?

4. Stopping Point Two: When Mike said "Comets are destroying the moon" what did you think? How did you decide your response? What do you think he understands about comets now?

5. Stopping Point Three: When Doug talked about there being more meteors on the back of the moon because the front of the moon was filled with lava what did you think? How did you decide your response? What do you think he understands about meteors and craters now?

6. Stopping Point Four: When Barbara said "It takes a whole day for the Earth to get around the sun" what did you think? When Phil followed up with "It takes 24 hours for the sun to get around the Earth" what did you think? How did you decide your response? What do you think they understand about the revolutions now?

7. Stopping Point Five: When Randy asked "Is God really alive?" what did you think? How did you decide your response? What do you think he understands now?

8. Stopping Point Six: When Trenton talked about stars being made in a special place in space, what did you think? How did you decide your response? What do you think he understands about star formation now?

9. Have (Will) you used (use) any of the student ideas in your lessons? How?

Intern Teacher—VSR Interview Protocol

Setting the Scene

We are going to be watching a video-tape of your moon and meteorite lesson from your astronomy unit. I have some questions to ask you about your teaching, and have some stopping points selected at which to ask those questions. You should also feel free to stop the videotape at any time and discuss your teaching or thoughts about what was happening, especially at points where you were making instructional decisions.

1. What were your goals for this lesson? Given that astronomy is an abstract concept difficult to understand, what do you expect students to understand about the moon and meteorites? How do you attempt to make these concepts accessible to children?

2. In what ways did you expect students to respond to your prompt? What did you think students already knew about the moon and meteorites? What did you think they did not know about the moon and meteorites?

3. Stopping Point One: When the students were arguing about the side of the moon with more craters, what did you think? How did you decide your response? What do you think he understands now?

4. Stopping Point Two: What did you think when Roy stated that a "meteorite is made of gas, metal, and rocks." How did you decide your response? What do you think he understands now?

5. Stopping Point Three: When Jaime explained that an asteroid was made of ice rock, and metal, what did you think? How did you decide your response? What do you think Ross and Jesse understand now?

6. Stopping Point Four: When Nat and the others were talking about part of the Earth coming off and going into orbit to make the moon, what did you think? How did you decide your response? What do you think they understand about the moon now?

7. Stopping Point Five: When Justin mentioned that the tiny marble made a small hole, but it went deeper into the cornstarch, what did you think? How did you decide to respond? What do you think he understands now?

8. Stopping Point Six: When Randy responded that the bigger the meteorite, the bigger the crater, what did you think? How did you decide to respond? What do you think they understand about meteorites and the moon now?

9. Have (Will) you used (use) any of the student ideas in your lessons? How?

10. Is there anything else you would like to tell me about the lesson?

Post-instruction Interviews

Post-instruction interviews were used to assess what the students gained from the teachers' instruction and actions, as well as the teachers' perceptions of students' conceptions. All participants in the study were interviewed at the post-instruction interview. The post-instruction interview had a different focus for the teacher than the mid-instruction, stimulated-recall interview. This interview occurred at the conclusion of the unit of study. Its focus was on how teachers viewed their teaching during the unit and on their view of student knowledge gained during the course of the unit. The teachers' perception of student ideas was a focus of the interview. Again, the interview proceeded in an open-ended, yet semi-structured fashion. Specific questions that guided the interview were developed at the conclusion of the unit based on occurrences in the classroom during teaching. The protocol included astronomy content questions from the pre-instruction interviews. Both teachers and the teacher intern were interviewed. The following protocol guided the post-instruction teacher interviews.

Teacher Views of Student Learning/Student Ideas

1. How successful do you feel with teaching this unit?

2. What do you believe your students learned? How do you know what they learned? Upon what evidence do you base your views?

3. What do you think students understand about astronomy compared to what you wanted them to know?

4. What do you think your students understand about orbits compared to what you wanted them to know? What do you think they understand about gravity compared to what you wanted them to know? What do you think they understand about the moon compared to what you wanted them to know? What do you think they understand about stars compared to what you wanted them to know?

5. What impact did student ideas have on your teaching practice?

6. What might you have done differently given more time or resources?

7. What has been the effect of this study on your teaching?

8. Is there anything else you would like to tell me about teaching this unit?

Teacher Goals:

1. What is astronomy?

2. What kinds of jobs might people have if they studied astronomy?

3. Can you tell me the names of the planets? Which do you think is the largest? The smallest? Which is the hottest? The coldest?

4. Can you draw me a picture of how the planets are in the sky? (Provide paper, pencils, crayons.) Can you put the sun in your picture? Where would it go in relation to the planets you have drawn? (Probe for names of planets the student has drawn.)

Benchmarks Goals:

5. (Provide a new sheet of paper.) What shape is the earth? Can you please draw a picture of the earth? On your drawing, please point to where you stand on the earth. (Using the child's drawing.) What if you dropped a ball—which way would it fall?

6. What kinds of things do you see in the sky during the day? (Do you ever see the moon in the sky during the day? When? What about comets or asteroids?) What kinds of things do you see in the sky at night? (Do you ever see the sun in the sky at night? What about comets or asteroids?)

7. (Provide a variety of sizes of balls.) Please choose one of these balls to be the sun, one to be the earth, and one to be the moon. Does the sun, earth, and moon move in space? Can you show me how they move using the balls? (Provide a new sheet of paper.) Can you please draw a picture of how you think they move in space?

8. Does the moon always look the same in the sky? Why does it sometimes look different? What different shapes have you seen? Can you please draw some of those shapes? Is there any order to the way the moon changes shape? How long does it take (if there is an order) for the moon to look round again?

9. Tell me what you know about stars. How many stars do you think there are? What are stars? Are they all the same brightness? Why or why not?

10. Is there anything else you want to tell me about astronomy?

Selected students who participated in the pre-instruction interviews were included in the post-instruction interviews. Student interviews focused on perceptions students had about their classroom instruction as well their current ideas of the science content. All questions in the pre-instruction interviews were included to note any differences in response that may be attributed to instruction. Students were interviewed for their content knowledge, and for their perceptions of teaching practices. The following protocol guided the post-instruction student interviews.

Teacher Goals:

1. You have been studying astronomy. What is astronomy? What kinds of things did you learn about?

2. When you grow up what kinds of jobs might you have if you studied astronomy?

3. Can you tell me the names of the planets? Which do you think is the largest? The smallest? Which is the hottest? The coldest?

4. Can you draw me a picture of how the planets are in the sky? (Provide paper, pencils, crayons.) Can you put the sun in your picture? Where would it go in relation to the planets you have drawn? (Probe for names of planets the student has drawn.)

Benchmarks Goals:

5. (Provide a new sheet of paper.) What shape is the earth? Can you please draw a picture of the earth? On your drawing, please point to where you stand on the earth. (Use the child's drawing.) What if you dropped a ball—which way would it fall?

6. What kinds of things do you see in the sky during the day? (Do you ever see the moon in the sky during the day? When? What about comets or asteroids?) What kinds of things do you see in the sky at night? (Do you ever see the sun in the sky at night? What about comets or asteroids?)

7. (Provide a variety of sizes of balls.) Please choose one of these balls to be the sun, one to be the earth, and one to be the moon. Does the sun, earth, and moon move in space? Can you show me how they move using the balls? (Provide a new sheet of paper.) Can you please draw a picture of how you think they move in space?

8. Does the moon always look the same in the sky? Why does it sometimes look different? What different shapes have you seen? Can you please draw some of those shapes? Is there any order to the way the moon changes shape? How long does it take (if there is an order) for the moon to look round again?

9. Tell me what you know about stars. How many stars do you think there are? What are stars? Are they all the same brightness? Why or why not?

10. Is there anything else you want to tell me about astronomy?

Student Perceptions of Teaching Practices:

1. What does your teacher like you to do when it is time for science?

2. What does your teacher do to help you learn about science?

3. What did your teacher do to help you learn about astronomy?

4. What do you do that is like what a scientist does?

5. What would you do if you wanted to know more about astronomy?

6. Do you share your own ideas about science in class?

7. Is there anything else you would like to tell me about how your teacher helps you learn science?

The Researcher

The researcher was the primary instrument of data collection. A description of the researcher's background, views toward teaching science, views toward student ideas, and knowledge of the content, is important in helping the reader to interpret the results.

The researcher is a former primary teacher, with four years of experience teaching first, second, and third grades. She has a Bachelor's degree in Psychology and Master's degree in Elementary Education. She is currently a doctoral student in science education at a Northwestern University. She has taught science methods courses for preservice elementary teachers. Prior to becoming a teacher, she used her degree in psychology for her work in management in a department store and as a personnel director.

She has strong views about how science should be taught in the elementary schools. While she believes that hands-on explorations should be a major element, it must not be the only component of effective elementary science teaching. Simply having students manipulate equipment is not sufficient in helping students learn science. Equally, if not more importantly, the researcher believes students come to the classroom with their own ideas about science. She believes it is important for the teacher, as well as the students, to know those ideas. She thinks it is important to hold discussions about the meanings being made by students of science explorations. She wants students to know their own ideas and to be able to describe them to other students. She wants them to know that ideas can change in the face of new evidence. She believes that elementary teachers generally have a strong background in language arts and can use this expertise to help them orchestrate discussions and develop writing assignments that will enable them to identify and develop student ideas toward scientific accuracy. To control for her own biases, the researcher intentionally searched for negative examples for what she believed was happening. For instance, if she believed the teacher was collecting ideas by having students write them in journals, she checked to see how the journals are used. Collection of student ideas through written communication would not be taking place if the students were not expressing ideas in journals, or if the teacher did not read the journals. The researcher was aware that her biases can affect interpretation of data. She consciously searched for teaching episodes that show effective teaching of science whether or not the teachers are eliciting or aware of student ideas.

The researcher believes students come with their own conceptions about science topics to her classroom. Most primary students do not have a complete scientific view of content areas. Thus, she believes conceptual change is necessary; she believes students must undergo conceptual change from their preconceptions toward the scientific convention. However, she remains unconvinced that all conceptual change strategies, as described in the current research, are effective at producing conceptual change. She believes practicing classroom teachers would be unable to use many of the strategies efficiently as described. She believes practicing classroom teachers with a background in science and in helping students develop conceptual understanding would design their own more effective and efficient strategies for identifying student ideas, implementing instruction, and assessing changes in classroom practice.

In response to teaching methodology questions that were asked to teachers, the researcher stated that physical science is her favorite topic to teach at the primary grade levels. It is enjoyable, exciting, and offers opportunities for students to explore their understandings in a hands-on, minds-on, fashion. The subject least enjoyable for the researcher to teach is social studies, simply because the researcher believes she holds little knowledge of social studies concepts and is not interested in increasing her knowledge to improve her teaching of social studies. During science instruction, the researcher always obtains the students' understandings through journal writings and both large and small group class discussions. The researcher also videotapes small group discussions while they are engaged in activities, so she can later view them and obtain an understanding of student thinking. Science units in her class last approximately eight weeks, taught on a daily basis. The researcher's goal is for students to develop a more scientific understanding of concepts, though she is aware young children will not develop fully scientific understandings. Another goal is for students to develop positive attitudes toward science.

In response to questions regarding content knowledge, the researcher described her own knowledge of astronomy. She answered the questions posed to teacher and students in the pre-instruction interviews. The questions and responses are divided into responses to address teacher goals, and responses to *Benchmarks* goals.

The first four questions are in response to questions developed to address teacher goals for instruction. The first question asks for a definition of astronomy, followed by a question regarding employment opportunities for those who study astronomy. She believed Astronomy refers to the study of celestial bodies. It includes the study of the Earth as a part of the solar system. Persons who study astronomy might become astronomers, engineers, design technologists, doctors, food technologists, astronauts, or any number of support positions for the space program. It is also possible that a person who has studied astronomer become a science writer who writes about astronomy for the lay person.

The next question asked for a listing of names of planets and the largest and smallest planets. There are nine planets orbiting the sun in the solar system. The planets, in order of distance from the sun, are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. The planets take increasingly long orbits around the sun, giving Mercury the shortest year, with 88 Earth days, and Pluto the longest, with 248

Earth days. Mercury is the smallest planet, while Jupiter is the largest. The planets remain in orbit because of the gravitational pull of the sun on each planet. Gravity's attraction is a function of the mass and distance apart of two bodies. The larger the masses of the two objects, and the closer together they are, the greater the gravitational attraction between them. Objects of large mass, such as planets in a solar system, exert much gravitational force between one another, in particular between the sun and the planets.

In response to the questions based on the *Benchmarks,* Earth is spherical. If a ball is dropped to the Earth, no matter where the researcher was standing, it would fall toward the center of the Earth. Persons standing on any part of the Earth do not fall off because of the Earth's gravity. There is a gravitational attraction between any two bodies. Because the Earth is much more massive than anything else on it, its gravitational force attracts all material bodies and keeps them on the planet. Objects of larger mass exert a force on smaller objects in their vicinity. The Earth exerts a greater force of gravity on all objects on it, so keeps them pulled toward its center and from floating off the planet.

The next question asks for a description of the day and night sky. In the daytime sky the sun, clouds, and sometimes the moon, are visible. It is not possible to see stars, other than the sun, during the day because the brightness of the sun overshadows. The moon is occasionally visible during the day depending on its orbit around the sun and Earth. If the sun is in such a position that it shines on part of the moon and the moon reflects that light in a direction that can be seen on Earth, it will be visible during the day. At night the moon is usually visible, as are the stars, and sometimes an orbiting comet may be visible. The sun is never visible at night, because if it were in the sky it would overshadow all other bodies and it would be daylight. Night and day are not dependent on the position of the moon, but rather are dependent on the position of the sun. It is day on the half of the Earth that is illuminated by the sun, and night on the half in the shadow facing away from the sun. As the Earth rotates, different parts of the Earth move into and out of the light of the sun, changing from day to night. Thus, as the Earth rotates, the part facing the sun at any point in time is in daylight.

In response to the question of how the Earth, moon, and sun move in the sky, the Earth orbits around the sun in one year. While it is orbiting, it is rotating on its axis. To completely rotate around its axis it takes 24 hours. The moon also orbits the sun with the Earth as it is orbiting the Earth. It is attracted by the Earth's gravity, which is why it is the Earth's satellite. Thus, it orbits the Earth about once every 28 days. It travels counterclockwise, the same direction as the Earth orbits the sun. The moon also rotates on its axis, but it takes exactly the same time to rotate once as to move once around in its orbit, so it always has the same side facing the Earth.

The next question asks whether the moon looks different in the sky. The moon's shape does look different in the sky. It changes in a predictable and regular pattern. The pattern is dependent on the portion of the moon that receives light shining from the sun. In fact, fully half of the moon is always facing the sun and receives sunlight. The portion of it visible from the Earth makes it appear to change. The beginning and ending of the lunar month is when the side of the moon facing the Earth is completely in shadow. As the moon orbits the Earth, the angles between the moon, Earth, and sun are continually changing. The portions of the moon facing the Earth that receive light change throughout the month. As the moon orbits the Earth it first becomes more visible, showing the shape of a crescent moon, a quarter moon, a gibbous moon, and a full moon. As it continues its orbit, less of it is visible in the sky, becoming gibbous, then quarter again, then crescent.

The next question requires a discussion of stars. There are many billions of stars. Stars are burning balls of gas, and most give out radiant energy as a result of nuclear fusion. They do not explode because they are so massive—they are held together by their intense gravitational fields. The next closest star to our own sun is so far away that it takes 4 ½ years for its light to reach us. Stars do not actually twinkle they only appear to do so due to the Earth's atmosphere. The stars' light needs to travel through the atmosphere to reach us, but the atmosphere is not still. Movement and temperature changes in the atmosphere cause small amounts of bending of the light from the stars. The light refraction causes the stars to appear to twinkle and vary in brightness.

Analysis of Data

In qualitative research, analysis is on-going and provides direction for data collection (Taylor & Bogdan, 1984). While in the field, data analysis consisted of noting patterns in collected data. Interview and video observation transcripts, as well as field notes, were reviewed and transcribed upon collection, and the researcher made written comments about any patterns becoming visible at the time. Throughout data collection, the researcher looked at the data and made records of interpretations in a researcher log. All interviews and classroom observations were transcribed the same day as they took place. Timely transcription allowed the researcher to keep what occurred fresh in her mind and be able to add comments, noted as such, in the transcripts that were recalled from the interview or classroom setting. If the researcher had waited to transcribe it would have been more difficult to recall what had occurred because other classroom events would have intervened.

The researcher formally analyzed all data at the conclusion of its collection. The process began with reviewing each transcript of interviews and classroom observations in totality. While reading the transcripts the researcher made notes in the margins of the transcripts. These notes became initial categories for the data. The initial categories were broad, such as "elicitation of idea," and "expression of idea." A second reading of the data allowed for narrower categories, such as "elicitation of idea in large group," "elicitation of idea in small group," "addressing idea by confrontation," "ignoring of expressed idea." Separate codes were developed for student ideas that were voluntarily expressed and ideas that were elicited by the teacher. For example, a transcript in which a student voluntarily said, "I think gravity doesn't work in space" was coded as "Student voluntary expression of ideas."

The categories were used to develop a description of the teachers' typical practices for eliciting and addressing students' ideas. These descriptions were made of each teacher and the intern. An individual profile was made of each teacher's classroom practice to describe how the teacher elicited ideas, how students expressed of ideas, and how the teachers responded to those ideas expressed. A comparison was then prepared of each teacher's practice. From the profiles a summary of practices was made to describe methods of eliciting, identifying, and addressing student ideas in classroom practice. A comparison was made among all classrooms, and similarities and differences were noted. All teachers differed greatly in their strategies and whether and how they addressed student ideas, though there were similarities among all. Reasons for the differences were sought. A comparison was made of differences among strategies across content knowledge levels and philosophies of teaching. A description was made of teacher practice related to student pre- and post-instruction content knowledge.

For purposes of data analysis, classroom observation data were the primary source. Interview data and collection of documents were important, particularly in triangulating an interpretation of the data. When discrepancies arose between the data sources, what was actually observed in the classroom took precedence. For instance, a teacher may state in an interview that she always listens to students speak. However, classroom observation may reveal that a student states an idea clearly, but the teacher does not recognize it, nor give any signs of hearing it. Thus, the classroom observation revealed that, at least in this instance, the teacher was not attending to student ideas. Therefore it would be necessary for the researcher to investigate why the idea was not recognized by the teacher. The discrepancy could provide important information in that the teacher could be open to children's ideas, but there could be other constraints that limit whether the ideas can be addressed.

As the data were read, emerging themes were noted and coded under titles that described them. The data were initially coded into broad themes, such as "recognition of ideas," but were then read and categorized again to further reduce the data into more specific themes pertinent to the research question, such as "methods of recognizing student ideas." The researcher made a list of student expression of ideas and the circumstances under which they were expressed, the teacher's recognition, or lack thereof, of those ideas, how the teacher did or did not respond to those ideas, and the effects of teacher actions on student learning. A profile of each teacher's classroom practice and instructional patterns was developed and presented in the results section.

An analysis of the pre- and post-instruction content knowledge of teachers and students followed. Content interviews were the primary source for this information. In the case of the teachers, a description was made of each individual teacher's knowledge of both their own goals for instruction and astronomy *Benchmarks* for second grade. The researcher and teachers have differing understandings of the content that certainly influenced the researcher's evaluation of student knowledge. Student knowledge was assessed in conjunction with district guidelines, taken directly from the *Benchmarks*. It is to the level of the *Benchmarks* that student and teacher content knowledge was held. Student content knowledge was compared and tabulated among all children interviewed. Student responses were coded to describe typical responses to questions. Atypical responses were also noted. A table of teacher and student responses was developed and is available in Appendix C and D. Student content knowledge was then compared to teacher content knowledge to determine whether the ideas were similar. Pre-instruction knowledge was then compared to post-instruction knowledge to see how and whether student and teacher conceptions had changed during the unit.

As a final step in the data analysis, the researcher discounted the data (Taylor & Bogdan, 1984). In the process of discounting, data were reviewed to see whether other explanations could be given for the results. The data were looked at in the context they were collected. First, data that were solicited and unsolicited were identified as such. Some responses were given to the researcher that were unsolicited by data collection methods; these responses from the teacher were valuable in determining how the teacher was identifying student ideas and in leading to explaining any trouble with uncovering ideas in a classroom setting, or in responding to student ideas. Second, the researcher's effects on the teacher were identified. It was presumed the researcher would have some effect on the teacher by virtue of the classroom observation, as well as interviewing teacher and students. The researcher's influence on the teacher is a limitation of the study, but a necessary one if classroom observation data are desired. Third, the researcher's comments and observations were noted as such in the body of the data collection, in particular field notes, as observer comments (O.C.). This coding allowed the researcher to identify any personal observations as such, and when analyzing the data, to be able to differentiate personal notes and inferences from actual observations.

Chapter IV

Results

Introduction

The purpose of this study was to investigate how children's ideas in science impact primary science teaching. Specifically the study sought to describe how experienced primary teachers identified and interpreted student ideas, how they responded to student ideas, and the effect of their responses on students' learning of astronomy. A comparison of teacher interpretations of children's ideas to the clinical definition starts the chapter. Profiles of each teacher include their background, astronomy content knowledge, beliefs about science teaching and children's ideas, classroom practices, and student pre- and post-instruction content knowledge. Summaries of each classroom follow. Next is a discussion to determine whether teaching strategies contribute to change in children's ideas. The final sections summarize and draw conclusions regarding the role of children's ideas in science for each classroom.

The teachers taught in a school that used looping for first and second grade. In the process of looping, students stay in one teacher's classroom for multiple grades. The students in the current second grade classrooms were in their second year with the same teacher where the advantage of remaining with the same teacher for two years is the familiarity with the teacher and classroom traditions and routines. In this environment each classroom was run smoothly. Neither the teachers, nor the students, were concerned with classroom management. Apparently management problems had been ironed out with the teachers and students sharing expectations of behavior and learning. The students in both classrooms seemed enthusiastic and interested in learning about astronomy and showed genuine pride in their work.

The teachers participating in this study did not use a professional curriculum from which to teach their astronomy unit. Instead, they pulled from many sources including many fiction and non-fiction children's literature books. The spring term in which the study was conducted marked the third time each teacher had taught the astronomy unit to second graders. In Teacher One's room (the teacher with 24 years of experience), the teacher provided all the astronomy instruction. In Teacher Two's room (the teacher with 10 years of experience), the teacher provided most of the astronomy instruction. Teacher Two had an intern teacher who provided additional instruction. Teacher One and Teacher Two are referred to as "experienced teachers" in the remainder of the paper. The Intern Teacher presented 12 lessons to illustrate various concepts, and also taught full-time during two of the eight weeks of instruction. The Intern Teacher consented to be observed and videotaped and her instruction is included in the analysis.

Interpretation of Children's Ideas

The term "children's ideas" is generally defined as experience-based explanations constructed by the learner to make a range of phenomena and objects intelligible (Wandersee, Mintzes, & Novak, 1994). Research has shown children's ideas to be stable and resistant to change (Carey, 1985; Driver, Guesne, & Tiberghien, 1985; Novak, 1988; Stepans, Beiswinger, & Dyche, 1986). As long as the idea serves the learner in making sense of the world, it remains an active theory for how the world works (Driver, et al, 1985; Osborne & Freyburg, 1985). Children's ideas develop early and, by the age of five or six, children have developed a robust and relatively coherent set of concepts about their world (Carey, 1985; Gardner, 1991; Piaget, 1929).

None of the teachers in the current study were aware of the research literature on children's ideas. However, by their actions, they shared the research definition of children's ideas. In general, they treated children's ideas as perceptually dominated, structured, coherent, and persistent alternative conceptions about the world. The teachers understood children to have ideas about a topic prior to formal instruction. The teachers recognized students did not hold accurate conceptions. Each experienced teacher stated the belief that student ideas influenced children's learning and the teacher's teaching.

Teacher One's definition of children's ideas included components of perceptual dominance, structure, coherence, and persistence. Several examples point to her definition of children's ideas. The following illustrates her conception of the perceptual dominance of children's ideas. What the child perceives is what she believes:

> One thing that might be impeding her was just the actual reaching around our balloon (as model of the sun)...I wasn't sure if I were imprinting her...about a rather odd orbit because of the lopsided balloon...I knew they were thinking the real sun looked off-balance like the balloon.

Teacher One recognized that students' perceptions of the balloon model were affecting how they were visualizing what the orbits of the planets did in space. Everything they perceived in the activity seemed to connect with what actually happened with orbits and the sun, moon and Earth, including a tilted sun because the balloon model was tilted. The following discussion illustrates Teacher One's conception of the structure of ideas, that a student had constructed an idea through thinking about an experience:

> I wanted to...understand what he was thinking [about the planets being closer to the sun on one end of their orbit than the other]...I wanted to know why he thought that. And I wanted to...see if there were...some fundamental knowledge that was leading him to believe that. I think he is capable of very remarkable thinking and he is constructing his concepts about how things work, and drawing conclusions all the time...When he talked about the differences in the orbit related to seasons I knew he had thought about this idea, and that he had used his experiences with the seasons to think about it...His idea was wrong, but he still "knew" about the orbit from his own thinking and experience.

She recognized the student had developed an idea from an experience, and that it was a reasonable, structured idea. It also illustrates Teacher One's belief that the idea was coherent, in that it made sense given the student's experience with the seasons and his thought about how they might occur given information about planetary orbits. The following statement illustrates Teacher One's conception of the persistence of ideas:

> What I would like people to understand about kids, even very bright kids, is that they are kids first and very bright second. So that very bright kid...he is still saying, "as the sun goes away." I think no matter how many times we revisit that...he, on a gut level, knows the sun goes away, no matter what words I make him learn.

The statement shows that she recognized students persist in their views of the world even though they may be able to state certain words that may make it seem like they have changed their conceptions. She recognized that all students, even those who seem the brightest, do maintain stable ideas about the world regardless of instruction.

Teacher Two's definition of children's ideas also contained components of perceptual dominance, structure, coherence, and persistence. She recognized students would not come to full scientific or adult understanding of concepts. She claimed to begin designing lessons after she understood what they knew. The following excerpt shows her understanding of how what students perceive is translated into what they believe occurs:

> I think what students see in their day to day lives affects what they learn. I expected that a student might ask about Superman...Maybe a child would ask about why we weren't studying planet Krypton...But we got pretty typical responses...But it is true that Superman could have come up because it has happened before.

The following exchange illustrates that Teacher Two believed student ideas were developed from experience and were coherent to the child:

> I wondered whether the student believed there was a star factory out there with some kind of assembly line where different parts get put on *like he might have seen somewhere* (author emphasis). I wondered what the picture looked like in his brain. I think even after the unit...*he still might put it together that way* (author emphasis)...He has an answer for what he knows, and doesn't need to find out more because he already thinks he understands the idea.

Teacher Two is relating the student's past experience with factories to his current view that stars were made in factory-like places in space. The exchange also illustrates that Teacher Two recognized the persistence of the child's thinking. Though she hoped he would have a greater understanding at the conclusion of the unit, she knew that without a reason to know more he would not necessarily build a new understanding.

The following comment also illustrated that Teacher Two concerned herself with how students develop and structure their ideas. She was excited that the student was drawing connections with what she had learned to new situations, but was interested in finding out more about how the student developed that idea:

> She said, "It would take four Earths to make one Jupiter. Where would she have heard it, or put it into a way that would be understandable to her?...Generally second graders cannot even understand the size of Corvallis, let alone the Earth sizes and how they would fit into a planet the size of Jupiter...Where she would have figured out that information?

Thus, it appeared Teachers One and Two held similar definitions of student ideas, and that they could recognize and interpret children's ideas in ways consistent with conceptual change teaching.

The Intern Teacher's definition of student ideas differed from the experienced teachers and from the clinical definition. Her interpretation of student ideas was that students could become "experts" in areas they studied and their "expert ideas" could be shared with their peers. Her interpretation did not include all components of perceptual dominance, persistence, coherence, and structure as would be found in a clinical definition of student ideas. She could discuss how abstract concepts needed to be made concrete for second graders, but did not provide examples, so it was unclear if she actually understood the significance of her statement:

> You have to make it age appropriate. They need the concept to be concrete, and some things are too abstract. Especially with astronomy. Many of the concepts are abstract. So actually a lesson needs to be concrete.

The Intern Teacher did seem to consider that students' conceptions were built into structures, that she called "schemas":

> They'll get astronomy again. They will need it. This will just give them a basis, and a schema about comets.

Though she recognized that students would not retain all the science they learned in their studies, she attributed it not to the persistence of student ideas, but to the fact that they would forget what they had learned:

> Some things kids will forget…I don't think it is a failure of the teacher or the student. They just forget what they learn.

The Intern Teacher believed students gained ideas and conceptions through activities and worksheets that she gave them. Student understanding was related to remembering the facts they learned from the activities or worksheets, not necessarily to a set of coherent thoughts. This recitation of facts as evidence of understanding is illustrated in the statement below:

> We had just done that page…so I was hoping someone would remember...he remembered!…I just wanted to see if they still knew it.

Thus, while the experienced teachers seemed to share an interpretation of student ideas similar to the clinical definition, the intern teacher did not. She did not have in her definition the components of persistence, coherence, and structure.

Given the interpretations of children's ideas for each teacher, the following sections provide profiles of each teacher and each classroom in how they elicit and address those ideas in instruction.

Teacher One

Teacher One holds a Master's degree in early childhood education. She has 24 years of teaching experience, eight of which is at the second grade level, and eight at the first grade level. She has experience teaching high school and college mathematics courses. She also has experience teaching special education. She considers her specialty reading and enjoys particularly teaching the primary grades in particular because her skills in reading are used to their best advantage. She has taught at her current school for sixteen years.

Content Knowledge

The content knowledge of Teacher One was fairly substantial and scientifically accurate. When she was unsure of a content question she felt comfortable stating her uncertainty. Her content knowledge did not change substantially over the course of the study as evidenced by her post-instruction interview responses. All pre-instruction responses for teachers and students are given in Appendix C and post-instruction are summarized in Appendix D.

The protocol began with questions about science content based on teacher goals. The teacher goals included understanding a definition for astronomy, knowing careers related to astronomy, and the ablility to name and draw the nine planets in order from the sun. Teacher One defined astronomy as a study of "all heavenly bodies," by which she meant all naturally occurring objects in space. The only career discussed by Teacher One was an astronaut. Teacher One accurately named and drew the nine planets using relative size in order from the sun.

Subsequent questions were developed from the *Benchmarks* (1993) for K-2 students to know about astronomy by the end of second grade. Teacher One agreed that the Earth is spherical and related the pull of gravity to the mass of objects. She believed that objects with greater masses had a greater pull of gravity but did not further explain her own ideas about gravity. She understood that a ball dropped on the Earth would fall toward the center of the Earth.

When selecting balls to represent the sun, moon, and Earth, Teacher One chose relative size as the criterion. She held the conventional idea about what caused day and night, stating that the side of the Earth that is rotated to face the sun is at day, while the other side is night. Regarding the movement of the Earth, sun, and moon in space, she talked about everything in space moving, with the universe expanding, claiming this knowledge by red light tests conducted by scientists. She discussed the orbiting of the Earth around the sun and the moon around the Earth, along with spinning on their axes.

Teacher One believed the moon does not always look the same in the sky. She described the changes in terms of phases of the moon. She discussed the moon phases in terms "waxing and waning" and drew her representations in a way that indicated a cyclical change (see Figure 2). She described the apparent change in the shape of the moon in terms of the Earth blocking some of the sunlight, and the moon getting only some of the reflected light.

Teacher One believed there is a countless number of stars. She stated that at the current level of knowledge it is impossible to know whether the universe is really infinite, or whether it is finite, and if it is finite, perhaps we could someday count the stars. She responded to the final question that allowed her to express her own ideas about astronomy

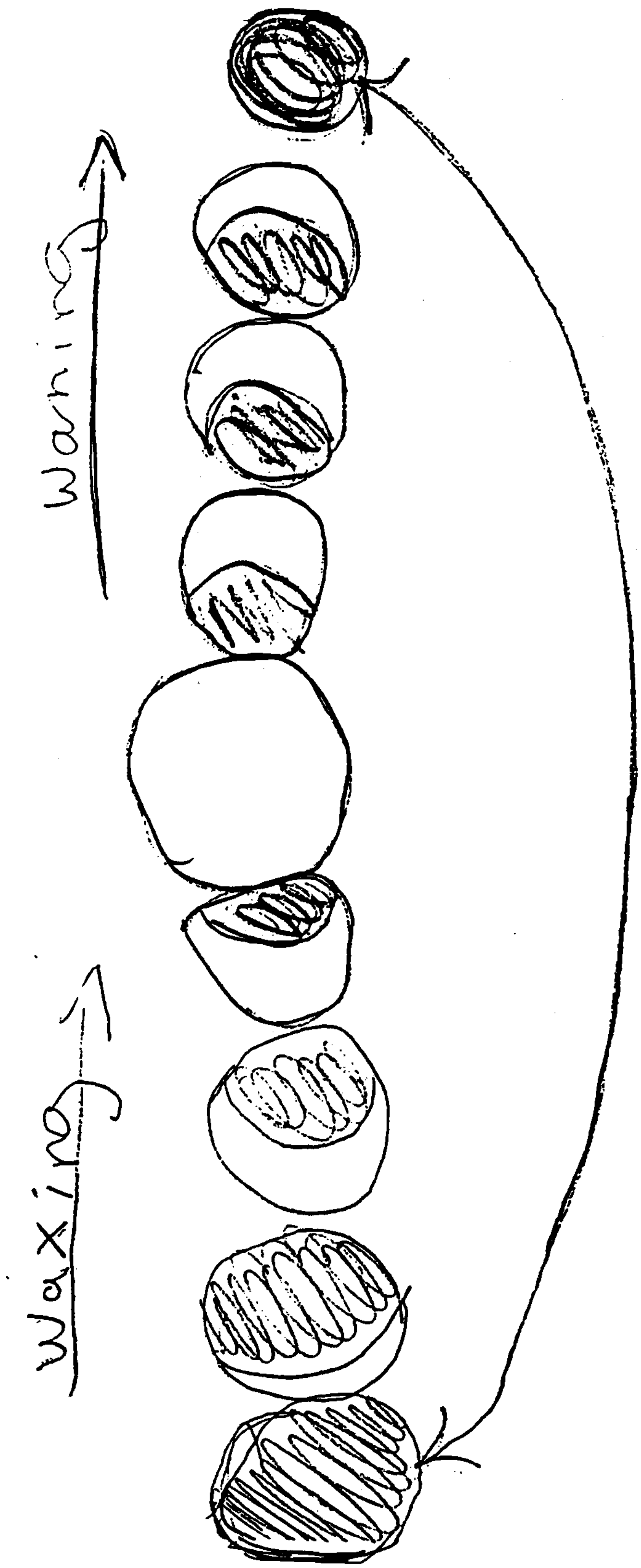

Figure 2. Teacher One's illustration of the phases of the moon.

in relationship to teaching astronomy to children. She discussed the importance of elementary teachers feeling confident in their abilities to teach a wide variety of science concepts and to continue fostering in children interest in knowing about the world.

Beliefs about Science Teaching and the Importance of Children's Ideas

Teacher One believed that science was an important, integral, part of the primary curriculum. She stated that children are most interested in non-fiction subjects. She believed that if she identifies student interests she can use them to help her develop their scientific and literacy skills. She was concerned that she could do a better job of teaching science if she had access to more equipment. She believed her main job as a primary science teacher was to help students develop positive attitudes toward science. She believed that by listening to student discussions, interacting with them, and watching them at play she could assess their knowledge and attitudes toward science. She cites the following example:

> I measure my success in science by how kids integrate and show their affective views toward science. I had girls play as scientists during our rainforest unit. They played at setting up experiments, inputting data. Role playing the experience that shows they know it has importance in their lives.

Teacher One believed her students' ideas were important to her and helped to guide her teaching. She claimed to get most of her knowledge of their ideas by listening to her students to help her plan activities to help them learn. She also wanted them to write their ideas about science content but believed having students talk about what they were learning, was the key to understanding what they know, and in helping students develop their own conceptions. She stated:

> Listening to them helps me to tailor to them individually. Some kids in my class are amazingly bright, and can grasp abstract concepts. Through listening to them I can understand how they are processing ideas and language. I can help them by showing them through other ways. If I just listen to them they will tell me all the information I need to know.

Teacher One did not talk about specific ideas she believed her students would have prior to instruction. She believed she would know their ideas once she talked with them. She thought they would have an awareness of a wide variety of sophisticated topics prior to instruction. She thought they would know, for instance, of black holes, wormholes, and space stations. However, she thought, though the topics would be sophisticated, their knowledge levels would be superficial. She believed her students would hold ideas that were not conceptually correct, such as whether the sun orbits the Earth. She believed they would need models to see how it works. She believed her students would "want the sun and moon to orbit the Earth—just ask them!" She based this belief on prior experiences teaching this unit.

Classroom Practices

Teacher One taught science every day. Nineteen one-hour lessons were observed, videotaped, and transcribed. The major task set out for students to complete was to select an individual area of interest and read about that topic, take notes about information that interested them, and write a report on the topic. Students were allowed to select any topic that interested them, from black holes to specific planets. Students were allowed to duplicate a topic selected by another student. The important thing for the teacher was that each student select a topic that interested that student enough to motivate him or her to read and write about that subject.

The astronomy unit lasted nine weeks. The unit began and ended with students sharing their ideas about astronomy in a large group discussion setting. The teacher brought in many astronomy children's books. She also required students to go to the public library to find additional resources. During the unit, comet Hale-Bopp was a prominent topic in the news and was clearly visible in the skies. One day's homework was for students to look for comet Hale-Bopp and on the following day a class discussion was held.

Throughout the unit, students worked daily on their research topics. They read from source books and took notes on items that interested them using their own words. Teacher One circulated the room and addressed individual ideas and answered questions about the individual topics. As students approached the end of their written work a large class discussion was held to develop a "key" or a way to organize the information into a report. Children generated a list of categories about which they could organize their topics. Students voted on categories that made the most sense in organizing and writing their reports. Students then re-wrote their notes to fit the categories selected by the class. After they re-wrote their reports, they sat with an adult, most often Teacher One, and read their report while the adult typed it.

The culminating activity for the unit was the publication of all research reports into a classroom booklet. The students made an official oral presentation of the reports to their classmates and invited guests. Each student read his or her own report, and all reports were presented to the invited group during a one-hour session. The astronomy morning marked the conclusion of the astronomy unit.

While the typical lesson included discussion and individuals working on their research reports, other lessons took place as well. Students made three-dimensional models of their topics to hang from the ceiling of their classroom. They selected drawings from books and then built models from paper to build and paint to represent their topic. No attempt was made to make the sizes of the models relative to one another, nor to hang them in any specific order from the ceiling. Another activity found the students decorating a backdrop for their presentations with paper models of their topics. Students also made crayon relief drawings of astronomical bodies and this artwork was hung in the classroom. It later served as covers for their report booklets.

Instructional sequence. Teacher One's typical teaching sequence can be described as a cycle (see Figure 3). She began each lesson with an initial Idea Invitation Question to invite discussion about the topic. The Idea Invitation Question was open-ended and designed to gather student ideas about a concept. Students readily respond 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 leading students to answer in a particular way. As the students worked independently, the teacher circulated from student to student. She raised the same initial Idea Invitation Question to understand individual student ideas. When she found an idea

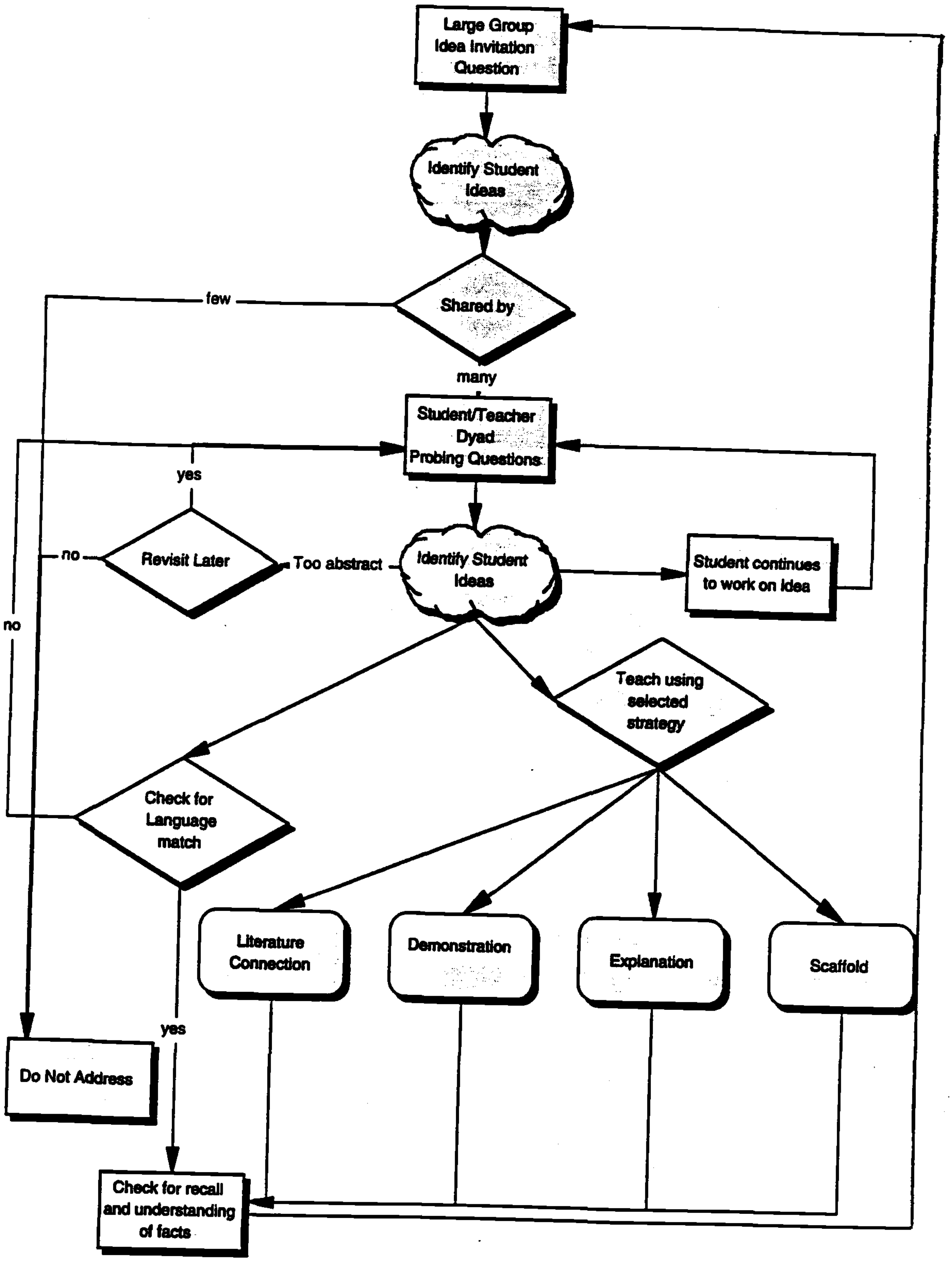

Figure 3. Teacher One Instructional Sequence—Cycle of Eliciting and Addressing Students' Ideas

was too abstract she dropped the line of questioning, though she sometimes revisited the ideas later. She strove to find out how students were interpreting her 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, which consisted of developing a lesson specifically designed to address student ideas; (b) Demonstration, wherein she provided a demonstration of 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. She asked factual questions to get their responses to determine whether their ideas had become more accurate.

In the next step of the cycle she again raised the question in a whole group setting. The initial Idea Invitation Question was again raised, and student responses were noted. If Teacher One determined students still had faulty understandings she often raised the question again in small group dyads. Figure 3 illustrates the cycle of elicitation and addressing of student ideas in Teacher One's classroom. A more detailed description of the cycle as shown in Figure 3 appears in the following sections on elicitation and addressing of student ideas. These sections are a result of triangulation data from student and teacher interviews, direct classroom observation and videotapes.

Teacher One's strategies for eliciting student ideas. Discussion proved the most important way Teacher One elicited students' ideas, whether working with the whole group or in a dyad with a student. For eliciting ideas Teacher One began the discussion with an initial Idea Invitation Question. The first lesson of the astronomy unit began with a discussion of "What do we already know about astronomy, or think we know?" and "What do we want to know more about?" She accepted responses from all students, and made sure each student responded by calling on volunteer and non-volunteer students. She reinforced that the list was composed of ideas and may not be entirely accurate, and throughout the discussion made comments such as "Are we sure everything we have written here is the truth?" She assured students their ideas were what she wanted and not factual information. When students disagreed on items she recorded both ideas and stated that. She left the conversation open to other ideas and made it apparent that it was not necessary that all students agree:

> Student A: The sun is a star.
> Teacher: Okay—the sun is a star (She records it on the board).
> Student B: The stars are distant planets very far away.
> Teacher: I am going to put a blank here so we can list other things stars might be.
> Student C: Stars are distant balls of burning gas.
> Teacher: Okay—I will put that. Since we don't all agree on what stars are then I will put question marks to show we are not quite sure what they are.

It was also the case that Teacher One's initial questions were not focused on obtaining correct answers from students because she did not correct their conceptions at this time, even when she knew the scientifically accurate information. In the exchange below the researcher initially questioned whether the teacher actually knew there had been no people on flights to planets, given her response to the student's initial statement. One of her goals was to make certain her female students knew they had a place in science, and her response to the statement indicated this focus. She continued using the child's phrase "past Pluto," though three lessons later on a different day she stated to the class "to my knowledge, no peopled ship has been past the moon":

> Student: No manned ship has been past Pluto.
> Teacher: What do we mean when we say "manned ship?"
> Student: People are on it.
> Teacher: So if we say "manned ship" does that mean only men are on it?...What is another way to include both men and women?
> Student: Peopled.
> Teacher: You're right. "No peopled ship have been past Pluto." What kinds of ships do you think have been passed Pluto?
> Student: Ones with no people.

Teacher One used discussion as her method for eliciting student ideas in small group and teacher/student dyads as well. She also used Probing Questions to check the depth of their understandings and to clarify her knowledge of their ideas. Her questions asked for students to ponder and consider why things happen the way they do. Consider the following:

> Teacher: If a regular orbit is a nice circle, then Mercury's does not. Do you think it could go in a square? (Student shakes head). Why...couldn't it go in a square?
> Student: Because maybe it couldn't go around the corners.
> Teacher: Yep, it would have some real problems going around corners. But it could still have an odd curve.

Through the interchange the teacher was probing and pushing the student to consider why an orbit would be unlikely to be square, or much other than circular. The teacher knew from this exchange that the student understood a square's shape, and the difficulty something would have making a turn sharp enough to go around a corner.

Teacher One used student ideas she elicited in dyads to prompt large group discussion. She cycled abstract ideas through her classroom over and over again. Some concepts that repeatedly arose and were addressed in small and large group discussions were gravity, relative sizes, and relationship of Earth, moon, and sun. The teacher used student responses in large group discussions to decide which students to have further conversations with in small groups, or whether to continue along that line. Some ideas were considered too abstract both in large and small group settings. These concepts, such as wormholes, were generally dropped from the discussion. Some concepts that were shared by many of the students, such as the sun and moon causing day and night, the teacher continued to revisit with her class. Using models the teacher illustrated the movement of the Earth and moon around the sun. Ideas uncovered in small group discussions were often taken back to the whole class to discuss as a group so the teacher could gain more understanding of student thinking and allow her to know if a sufficient number of students shared the idea to warrant further exploration. Teacher One stated that when many students did not hold a good understanding of a concept she was more likely to continue to teach the concept than if just a few students still had misunderstandings.

Teacher One's strategies for addressing student ideas. Teacher One's students often voluntarily expressed ideas by bringing up topics related to the astronomy concepts at hand. Rarely were the ideas students voluntarily expressed scientifically accurate. In every case the teacher encouraged the student to share the idea:

Student: I have something just too impossible.
Teacher: Please tell me.
Student: More than 1000 planet Earths can fit in the planet Jupiter.

Teacher One often expressed the concern that often "child language" did not match "adult language." She acted on this concern by probing for the child's definition for whatever term was being used:

Student: You know, the moon switches places with the Earth...It does that to make day and night.
Teacher: It does? What do you mean it switches places with the Earth?
Student: Like here it is, closer to the sun (She is holding two pencils as props). It moves from one side over, and then it switches.

Teacher One did not indicate to the student whether she was right or wrong, but acknowledged the response, which left it open for the student to expand on her idea. The teacher was able to gain information about the child's conception and to encourage more sharing of ideas. At this point the teacher decided to confront the child's thinking with an additional question. The question was a departure from the statements and responses given earlier by the teacher:

Teacher: Have you ever seen the moon in the sky during the day?
Student: Yeah, when it is turning nighttime.
Teacher: You think of that some more. We will use some clay to talk about how the moon, sun, and Earth work together and how it makes day and night. You can explain to me then how you think the sun and the moon switch places, and I can explain it to you how I think they work.

Teacher One left the conversation open for more discussion. She encouraged the child to share her thinking by acknowledging her statements. She did not reinforce ideas, but promised a future discussion with manipulatives that would help the teacher understand the student's idea, and to help the student understand the teacher's idea. The teacher was careful to always use the word "think" so students would not feel they had to provide the only accurate answer. The term "think" was less restrictive than the term "know." It stressed interest in student thought rather than predetermined correct responses. By addressing ideas that were voluntarily expressed in ways that showed the ideas were valued, heard, and even used in future discussions and activities, Teacher One was encouraging students to continue expressing their ideas about science content.

Teacher One used Idea Invitation and Probing Questions to elicit student ideas. For elicited ideas she had several responses. She endeavored to discover how many shared the idea. If the idea was held by a small number of students it was dropped from further exploration. Further probing of the idea was also dropped if it was found to be too abstract. As discussed in the section above, the teacher used ideas obtained in large group discussions to elicit individual ideas in teacher/student dyads. At this juncture she also decided how to respond to the student's idea based on the student's response to her question. If the idea seemed to be too abstract for the child after asking probing questions, she either dropped the discussion, asked the student to consider thinking about it and revisited the idea with the student later, or chose to explicitly teach the concept to the student. If the teacher found the idea to be shared by many students, she sometimes chose to explicitly teach the concept in a whole group setting, using strategies of Demonstration, Lesson Development, Literature Connection, Explanation, and Scaffolding.

Demonstration was used to present scientific information using drawings or representations of the concept as well as manipulatives. Teacher One explained as she manipulated or shared the drawings. The following example of Demonstration is also an example of Lesson Development because it was specifically designed to address student ideas about orbits and what it meant for Pluto and Neptune to "switch places." Teacher One drew a set of planetary orbits around a sun on a piece of posterboard. She glued small pictures of the planets in orbit around the sun, not all lined up in a row. She used small pom poms as model planets to move around the orbits, and then asked students to move the model planets around the orbits on her drawing and in patterns at their desks.

Teacher One used the drawing as a manipulative as well. She asked students to individually manipulate a toy planet around the orbits she had drawn on the poster board. She again used the posterboard drawing to encourage the students to think about scale in the interchange that took place while students were manipulating the toy planets:

> Teacher: Okay—let's talk about the orbits. When I was at the triangle table we talked a little bit about my drawing not being to scale. Does anyone know what that means, "to scale?" …
> Student 2: The planets aren't really that close to each other. The sun is really lots bigger.
> Teacher: She is right, exactly. If I made the picture with the sun in scale I wouldn't have room for the rest of the planets. By my drawing I am not trying to show their distances or relationship to the sun, just their orbits. (Continues calling students to demonstrate). Now we are on the two most incredible planets, Pluto and Neptune. Let's see. Student 1, you start where your planet is, and Student 2 start where your planet is. Which planet is farther away right now?
> Student 2: Pluto (continues moving planet models)
> Teacher: Which is farther away right now?
> Student 2: Neptune.

The teacher used the posterboard drawing to illustrate why it appeared that Neptune and Pluto switch places. "Switch places" was a term used by students to describe the change in the orbits of the two planets. Teacher One illustrated that it was the shape of the orbit that made it seem like the planets were "switching places," not that they were actually moving on one side or the other of each other.

> Teacher: When we talk about the planets trading places, do they really like switch places? No they don't, they move around each other, and what happens is Pluto's orbit is goofy in that the rest of the orbits are more circular, but Pluto's is highly elliptical, meaning it is shaped more like a bit fat cigar than a circle...Sometimes the orbit is closer to the sun than Neptune's. They don't really switch, they don't move around each other, they don't stand in front of each other. So even though they trade places (She moves back and forth with a student) they are not doing this—planets are just moving around their own orbits.

The teacher demonstrated with the whole class and next asked students to demonstrate their understanding individually as she circulated around the room. After Teacher One talked with individuals and small groups, she reconvened the class for a large group discussion about the demonstration. The purpose of the discussion was to debrief the lesson and provide closure to the activity. Teacher One assessed student understanding of the orbits.

> Teacher: Whose orbit changes, Pluto or Neptune?
> Students: Pluto.
> Teacher: Yeah, and it isn't that it changes its orbit, its orbit is shaped so it changes its position in relation to the sun. At the furthest away parts of its orbit it is farther away from the sun. At the closest parts of its orbit it is closer to the sun than Neptune. We say it trades places with Neptune, but it really doesn't.

The entire lesson shows how Teacher One used Demonstration to illustrate a concept to address ideas she had previously elicited. She began with a manipulative and visual aid, presented scientific knowledge through her explanation, and asked students to describe their own thinking about what was happening. She alternated between large and small group discussions to assess changes in understandings and asked students to use manipulatives to demonstrate their idea of how the planets move about in orbits and what it really means when people say that Pluto and Neptune "switch places." A point Teacher One continually brought up in interviews and discussions was the difference between "kid language" and how children interpreted what adults meant with their language. She saw one of her roles as helping children reconcile the difference between their interpretations of adult language and their own "kid language." Helping them to understand what Pluto and Neptune "switching places" meant, is an example of this instruction.

Another way Teacher One disseminated scientific information was through Literature Connection, consisting of reading children's non-fiction tradebooks. She found reading non-fiction tradebooks to be a good way to explain information, particularly information she was not absolutely sure of herself. She had a wide selection of non-fiction books in her classroom that she had collected over her years of teaching and from the school and public libraries. She read a non-fiction book almost every day. Non-fiction tradebooks were used in dyad settings as well to help the teacher answer questions individual students asked. She often did not finish reading a statement in the book but allowed the students to fill in with the concluding part of the sentence. In that manner she encouraged students to recall information and their own ideas about the concepts in the books. The exchange surrounding the moon being a satellite rather than a planet was prompted by one student's earlier statement that the moon was a planet because it also went around the sun. The lesson below shows the typical sequence of reading, and discussion about the book.

> Teacher: I will start reading now. (Reads) Look up in the sky and you will see… (holds up book with large illustration)
> Students: Sun.
> Teacher: The sun is a huge…
> Students: Ball of fire, ball of burning gas, star
> Teacher: All of those would be right. (Continues reading) "Star. The sun is made of…"
> Students: Burning gas.
> Teacher: What are the objects called that move around the sun?
> Students: Planets
> Teacher: Good. Somebody asked me this week why the moon wasn't a planet. Why don't we call the moon a planet, why do we call it a satellite instead of a planet? Planets orbit a what?
> Students: Sun, Star.
> Teacher: Yeah, a star. What do moons go around?
> Students: Planets.
> Teacher: The difference between a moon and a planet is what they go around.

In this interchange the teacher was able to address students' ideas, that were previously expressed, about the sun as a star and to confront an idea that the moon was a planet. It seemed that most children agreed on the difference between a moon and a planet, and thus, the teacher continued with her lesson.

Another method of explicitly teaching science content was to use Explanation. During Explanation, the teacher always used questioning to help assess student understandings of the concepts she was explaining. In the explanation the teacher was giving below, she used student understandings of the Earth's movement to help them understand why the stars appeared to move across the sky.

Teacher: Stars are not in orbit. The universe is expanding. The stars are moving, but you would not be able to observe that movement. The reason you think the stars are moving across the sky is the same reason you think the sun is rising and setting. Is the sun moving around the Earth? (Chorus of "no") The stars aren't moving either. What is happening to the Earth?
Students: It is turning.
Teacher: Right—it is moving around the axis, so that makes it look like the stars move with the season, but they're not. There aren't really changes with the constellations, they are also occurring with the movement of the earth around the sun and the movement of the earth around its axis. How much time does one whole orbit equal? What do we call that?
Students: A year.
Teacher: Very good. Are all years the same length? (Chorus of "no"). A planet closer to the sun will have a year longer or shorter than Earth's? (Chorus of "shorter"). A planet farther from the sun will have a year longer or shorter than earth's (chorus of longer)? Good job. Why?
Student: The path is longer.

Teacher One used student understandings of every day objects to help Scaffold their understandings of new ideas. In the interchange below the teacher found an idea the student understood—the idea of pierced ears—to help the student understand what it meant for something to be pierced. The lesson is taking place with an individual student during the student's research of her own topic.

Teacher: (Reading student's notes). "Cloud piercing radar records data…"
Student: Kind of like on a computer.
Teacher: Right, it is like information. Sometimes computers translate that data. That means that this space probe has been able to send back more detailed pictures of Venus than anything before.
Student: Probably they wanted to land on there to see what it is like. We wanted to see what is under the clouds.

Teacher: Very good. How come Magellan can take pictures through the cloud. Do you know what piercing is? What are pierced ears? Like when your ears have little holes in them and the earrings go through? So Magellan used cloud-piercing radar...The radar...pierces the clouds, touches the surface, and bounces back and records data about what Venus is like.

Thus, Teacher One had several ideas she cycled through small and large groups through discussions. She made decisions whether to continue discussing the idea, allowing it to drop, encouraging the student(s) to continue thinking about the idea, or to explicitly teach the concept using the variety of strategies discussed.

Student Knowledge

To track teacher effects on learning outcomes, student content knowledge was assessed with pre- and post-instruction interviews. Prior to instruction 10 students from each classroom were selected by each teacher to participate in pre- and post-instruction interview designed to assess student knowledge. A more detailed list of teacher and *Benchmarks* (1993) goals appear in Appendix B. A comparison made of pre- and post-instruction interviews enabled a determination to be made about the success of each teacher at helping students attain both teacher and *Benchmarks* (1993) objectives. Teacher goals were for students to know:

- A definition for astronomy
- Astronomy-related vocations
- The names of the planets in order from the sun
- The relationship of the Earth, moon, and sun.

The *Benchmarks* (1993) goals were for students to know:

- The moon looks a little different every day, but looks the same again about every four weeks.

- The sun can be seen only in the daytime, but the moon can be seen sometimes at night and sometimes during the day
- There are more stars in the sky than anyone can easily count, but they are not scattered evenly, nor are they all the same in brightness and color.
- The sun, moon, and stars appear to move slowly across the sky

At the post-instruction interviews students defined astronomy as a study of space. Students typically responded that persons who studied astronomy could hold jobs as astronauts or astronomers. A few students mentioned ground control personnel. These responses did not differ from pre-instruction responses. However, at the post-instruction interview all students could name, make illustrations, and label the planets in order from the sun. Students could not name, illustrate, or label the planets at the pre-instruction interview.

The six remaining questions are now summarized, in relation to the *Benchmarks* (1993) goals. All students in each classroom believed the Earth was round. This belief represented no change from pre-instruction knowledge. However, all students responded that gravity holds things to the Earth, where at the pre-instruction interview only seven students held that belief. Students in Classroom One seemed to have a more accurate understanding of gravity after instruction given responses like "the amount of gravity depends on the mass of the planet—bigger mass has more gravity." However, it was evident that most students did not have an accurate understanding of gravity, but that it was the force that held us on the planet, either by pushing or pulling on us. All students in Classroom One believed a dropped ball would land at your feet, and that gravity would let a ball roll, but not fall off the planet. Seven of the 10 students drew pictures and described gravity as pulling toward the center of the Earth. The other three students believed gravity pulled things down, toward the "bottom" of the Earth.

Invariably, all students interpreted the question that asked for a response to what can be seen in the sky at night and during the day, as asking what creates day and night at the pre-instruction interview. Students generally had inaccurate conceptions of day and night. Three students believed the sun would move to the other side of the Earth so it would be night on our side. Three additional students believed the moon made night, and the sun made day. One child personified the sun, stating it would be night when the "sun went to bed." The moon and the clouds blocking the sun was a response given by one student as a description of why it became night. At the post-instruction interview students did not misinterpret the question. This time students responded with different celestial bodies they could see at day and night. Most conceptions were accurate, with most students in both classrooms responding that they could see the sun in the day, but not other stars because the brightness of the sun makes it difficult to see other stars. One student believed she would be able to see other stars during the day if she looked carefully enough. All students noted they could see the stars and moon at night. All students believed they would never see the sun at night, and three believed they could sometimes see the moon during the day.

Students were asked to select balls to represent the Earth, moon, and sun, and show the interviewer how they moved in space. Nine students selected the balls according to relative sizes and accurately selected the largest ball to represent the sun, the next size to represent the Earth, and the smallest size to represent the moon. The other student used color as a way to select the balls, calling the large, blue ball the Earth, the small, red ball the sun, and the smallest, white ball the moon. There was no change at the post-instruction interview. Students had more accurate conceptions of the movement of the three bodies at the post-instruction than in the pre-instruction interviews. In general at the post-instruction interview most students believed the Earth rotates around its axis and revolves in an orbit around the sun, with the moon rotating around its axis, revolving in an orbit around the Earth. Most students knew the length of time it takes for the Earth to rotate and make a day and for it to revolve around the sun and make a year.

None of the students believed the moon looked the same in the sky each night. This belief did not change over the course of the unit. At the pre-instruction interviews seven students agreed that the moon does not really change shapes, it just looks different in the sky. One seemed to have a fairly conventional viewpoint of why the moon looks different in the sky, believing it was light from the sun shining on the moon in differing amounts, causing parts of the moon to show up in the sky. About half the students (four) believed something in the sky covers the moon, causing parts of it not to be seen on the Earth. What covered the moon could be clouds, other planets, the darkness, or the sun. One student realized it could not be the clouds because sometimes clouds were not in the sky all the time when the moon looked smaller, but offered no other explanation. One student believed parts of the moon went away and then came back, while one thought it "sucked itself in," and modeled that process by pushing into a Nerf ball to make it change shape. One student believed the shadow of the Earth fell onto the moon, causing it to look smaller. One child believed comets would hit the moon causing parts to break off and making it look differently. This student did not speak of the moon looking differently in terms of phases, but in terms of permanent changes to the surface of the moon, by new craters being formed through comets hitting the surface. In Classroom One there was no formal instruction regarding the moon. There were no activities and students were not asked to watch the moon in the sky. Only one student at the post-instruction interview continued to believe parts of the moon broke off and went away and came back to create changes in how the moon looked. Eight students believed the moon looked different because of shadows from the Earth or other planets, or from clouds blocking the moon, which represents no change from pre-instruction interviews. Only one student mentioned an order in which the moon looked like it got "skinnier and then thicker."

All students thought there were more stars than could be counted. One student gave a definite answer of "100." At the post-instruction interview there was no change in ideas, except the student now gave the response of "500." Students often believed that the stars could not be counted because there were stars on the other side of the Earth that could not be seen at any one point in time. Also, there was a general belief that there were so many stars that it would be hard to keep your place if you were counting them, and you couldn't count them in one night and would not know where to start counting again the next day. Nine students believed that stars were balls of gas and fire at the pre-instruction interview. All students believed stars were balls of gas and fire at the post-instruction interview. At the pre-instruction interview eight students believed stars were actually circular, but that people draw them with points because it makes it look like they are sparkling or that is just how they are drawn, not how they really are shaped. Nine students believed stars were circular rather than five-pointed at the post-instruction interview.

When students were allowed to tell anything they wanted about astronomy, only three students responded at the pre-instruction interview. Seven responded at the post-instruction interview. At both interviews students generally responded with factual information they had heard or learned, though one student at the pre-instruction interview explained his theory about why we changed the clock back in relation to the spinning of the Earth and daylight savings time.

In general, student knowledge improved from their experiences in their astronomy unit. At both settings most students had ideas they could share and discuss. All students could talk intelligibly about what they knew. What they knew was not always in line with current scientific ideas. Students in Classroom One appeared more willing to share and discuss their ideas, particularly as evidenced by their responses to the final question. However, students had more accurate conceptions to most questions than prior to instruction. The area at which they had their most difficulty was regarding why the moon does not look the same each night.

Summary Teacher One

Teacher One had strong interests and specialties in language arts. She believed science was an important and integral part of the primary classroom in helping students to study what was most interesting to them—their own world. Teacher One's knowledge of astronomy was satisfactory for most of the areas she taught and for the *Benchmarks* (1993) recommendations for K-2 learning. When she was unsure of an idea she freely stated her uncertainty, but recognized she could easily learn the concept. While most of her knowledge was scientifically accurate, she held an unconventional idea about the phases of the moon. She stated the Earth blocked some of the sunlight, thus the moon received only some reflected light, making it look different.

Teacher One taught science every day. Students spent time working on individual reports with the teacher circulating the room asking the students questions and interacting with them in ways that caused them to think about what they were studying. The teacher also spent time on whole group lessons to help students organize their writing. Their reports were published in a book and they presented them publicly.

Student ideas impacted instruction in Classroom One because the teacher endeavored to elicit those ideas and to address them in instruction. Teacher One seemed to interpret "children's ideas" in a manner that was in line with the definitions in the research literature. Her interpretation shared the qualities of perceptual dominance, coherence, structure, and persistence. Student ideas were an integral part of the classroom instruction in that they were repeatedly addressed in a variety of ways. Teacher One's classroom practices included a cyclical pattern of instruction. Regarding the research question of how primary teachers elicit ideas, she began each lesson with an initial Idea Invitation Question that garnered student ideas about a topic. Probing Questions followed to determine the number of students who shared the idea and the depth of their understanding. Students then worked independently as the teacher circulated the room, raising the same Idea Invitation Question to determine individual ideas. When students demonstrated an inaccurate understanding of the topic she reacted to their ideas by deciding whether to pursue the topic or let it drop. If she believed the concept was too abstract for the student she often let the idea drop. If she believed the student could gain an understanding on his or her own she asked the student to do so. When the idea was not too abstract she chose to react to student ideas by addressing them through strategies of Demonstration, Literature Connection, Explanation, Scaffolding or Lesson Development.

Her strategies for addressing student ideas seemed to have a positive effect on student learning. Student knowledge of astronomy improved over the course of the unit as evidenced by a comparison of responses in the pre- and post-instruction interviews. Students improved in their knowledge of gravity and what determines day and night. Students improved in their knowledge of what stars are made of and the shape of a real star versus the shape drawn to represent stars. Students did not change their perceptions in selecting models to represent the Earth, moon and sun, nor did they improve in their conceptions of why the moon looks different in the sky. At the conclusion of the unit more students shared their ideas when asked to tell anything they wanted about astronomy than in pre-instruction interviews.

Thus, Teacher One, with an interpretation of children's ideas that can be argued to be in line with research literature definitions, with satisfactory content knowledge and a desire to know and change student ideas, was influenced by those ideas. She was influenced to develop strategies to elicit and address student ideas that influenced her teaching practice. Her teaching practice that addressed student ideas seemed to positively effect student learning regarding students holding ideas more in line with scientific ideas.

Teacher Two

Teacher Two has a Master's degree in early childhood education and has taught for 10 years at grades one and two. She most enjoys teaching mathematics and language arts and searches for ways to combine both subjects. She was a 1994 nominee for the Presidential Awards for Excellence in Mathematics Teaching. All of her 10 years of experience teaching has been at the school she is now teaching. She is the lead instructor with Teacher One at math inservices conducted for primary teachers and is the lead author for the mathematics activity book both teachers wrote in 1994.

Content Knowledge

Teacher Two was concerned that she did not appear knowledgeable. She had difficulty responding to several of the questions. However, she was able to share her ideas for each question. She had more accurate responses at the post-instruction interview. She said she remembered information as she delivered lessons each time that she taught the unit.

The protocol began with questions about science content based on teacher goals. The teacher goals included understanding a definition for astronomy, knowing careers related to astronomy, and the ablility to name and draw the nine planets in order from the sun. Teacher Two called astronomy a study of "things in space." Her view of astronomy included the study of space travel and rocketry as she discussed helping her students to learn about what it might be like to live in space. Teacher Two wanted the students to know they could be astronauts as a career related to space. She also wanted them to know of other support careers such as geologists, engineers, and physicists who work in careers related to astronomy. She wanted them to think about what they were learning as purposeful for their futures.

Teacher Two had some difficulty naming all the planets accurately in order from the sun. She began to sing a song as a mnemonic and still could not recall the ninth planet until her Intern Teacher stated from across the room "It begins with an 'N'." The teacher then remembered the plane Neptune. She did not discuss any of the orbits and did not list all planets in the correct order.

Subsequent questions were developed from the *Benchmarks* (1993) for K-2 students to know about astronomy by the end of second grade. Teacher Two agreed the Earth was spherical and that gravity keeps us on the Earth. Teacher Two was unsure how gravity worked, and tried to explain gravity using many science terms, such as "pressure," "weight," and "force." She talked a bit about what it would be like to be on a planet with less gravity, but did not discuss her ideas about gravity. She was visibly flustered at explaining her ideas about gravity, stating she knew this question was the "gravity question," but was really unable to explain her ideas. She did understand that a ball dropped anywhere around the surface of the Earth would fall toward the center.

Teacher Two held conventional ideas about what causes day and night, stating that the side of the Earth that is rotated to face the sun is at day, while the other side would be night. She extrapolated to explain what might happen if the sun exploded, that pieces of the sun would go into space and "envelope other areas." She thought children might also talk about the sun exploding. However, no child discussed the sun exploding in response to this question.

When selecting balls to represent the sun, moon, and Earth, Teacher Two chose relative size as the criterion. She discussed the movement of the three in a traditional fashion, stating that the Earth and the moon spin on their axes and that the Earth orbits the sun with the moon orbiting it. She was unsure whether the sun rotated on an axis. She was unsure in which direction the moon and sun revolved. At this point Teacher Two mentioned being concerned she would look inadequate with her responses, showing lack of confidence in her knowledge.

Teacher Two agreed the moon does not always look the same in the sky. She described the changes in terms of phases of the moon. She drew the apparent changes in the moon in terms of changing toward one direction, increasing in size. She did not draw the crescent and gibbous phases in the other direction, indicating decrease in size (see Figure 4). She also held an unscientific idea about the phases of the moon, stating that the part of the moon that cannot be seen is in the shadow of the Earth.

Teacher Two thought it was impossible to count all the stars because some stars are being formed and others are dying out. Because of the continual change in numbers it would not be possible to count them. She stated stars were made of debris pulled in with gas. She agreed that stars were circular and thought it interesting that people do not draw them that way. She thought people probably draw the points on stars to represent solar flares coming off the balls of gas.

Teacher Two chose to respond to the final question, which allowed her to share what she wanted to add about astronomy. She responded by relating her ideas to teaching astronomy to children. She talked about wanting children to know more about astronomy than looking at the sky. She wanted children to know about all the advantages research in space has given to people on Earth. She discussed ideas such as dehydrated foods, new materials that can create comfortable mattresses for use on Earth, and medicines that can help the sick.

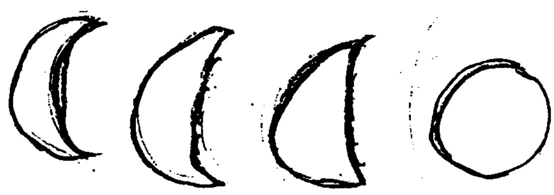

Figure 4. Teacher Two's representation of the phases of the moon.

<u>Beliefs about Science Teaching and the Importance of Children's Ideas</u>

Teacher Two believed science is important in a primary classroom because students come to school interested in science and in learning about the world. Science in the primary classroom can help build on and maintain student interest in learning. She endeavored to know in what they were interested, and used that knowledge to build her lessons. She believed there was no reason to wait to teach science until students are older because they can, and do, begin learning about their world from a young age.

Teacher Two believed her main task as a primary science teacher is to help students learn basic concepts and language they will need when they talk about those areas. Like Teacher One, she recognized the discrepancy between language young children use and how adults use the same terms. Other goals she had for her students to learn about science were learning to ask questions, collecting data, and developing research skills so they can answer their own questions. Answering their own questions in this instance seemed to relate more to literacy skills rather than science inquiry skills. However, she also wanted her students to know how to make observations and records.

Teacher Two believed student ideas were important in her teaching of science. She claimed they guided her teaching and she could use students' ideas as a way to guide student thinking to a more scientific understanding. She believed questioning strategies were important in helping students develop more accurate ideas:

> If you phrase the questions appropriately you will get the most wonderful information. If you phrase them as yes/no questions, right/wrong answers, you will get only that. If you ask more open-ended, thought provoking questions, you will get wonderful ideas, and make students think about

> their perspectives, and what they know about concepts and ideas…You, as the teacher, guide the thinking and what you are able to pull out.

Teacher Two did not discuss specific ideas about astronomy she believed her students would have prior to instruction but did recognize their conceptions would often be inaccurate, and even unrealistic. She stated that students had lots of curiosity about astronomy, so that would be a key in helping them develop more accurate understandings. She believed both genders are interested in astronomy, though sometimes it takes a special key to interest the girls.

Classroom Practices

Teacher Two taught science every day. Twenty-three one-hour lessons were observed, videotaped, and transcribed. Students in Teacher Two's class selected an individual area of interest to study. Each student was to read about his or her topic, take notes, organize the notes, and write a report on the topic. The teacher presented the students with a pre-selected list of topics for them to choose from. She asked for student input in adding topics to the list. No two students were allowed to study the same topic, with the exception of two "low" students who were assigned to work together. Teacher Two required one person to study each planet. If no one wanted to study a particular planet she waited until someone volunteered. Teacher Two 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."

The astronomy unit lasted eight weeks. The unit began and ended with students sharing their ideas about astronomy in a large group discussion setting. At the conclusion of the unit the teacher asked students to revisit their earlier ideas and give their updated versions of them. Each day during the unit students worked on their individual research topics. They had from one-half to one hour to read books and take notes about their topic. During the individual research period, Teacher Two circulated the room, reading with individuals, answering questions, and holding teacher/student discussions during which many of the students' conceptions were elicited. As students finished writing their notes they were asked to go to the computer and read their notes to an adult who typed and printed their reports. When Teacher Two helped with the typing, she often asked students questions that required them to gather more information.

The culminating activity was the publication of all research reports into a classroom book. The reports in the books were orally presented at an astronomy night. At the astronomy night students presented their research reports to invited guests. Students built a set and wrote commercials to use between sets of reports. The commercials also showed a developing content knowledge because the ads were for items that could be used for space travel or in some way connected with astronomy.

In addition to time for individual research, students were treated to an almost daily hands-on activity. The Intern Teacher exclusively delivered the hands-on activities. Topics for the activities were given to the Intern Teacher by Teacher Two, and the Intern received advice in planning the activities. Teacher Two often debriefed the activities with the class at the conclusion. The intern initially did not like the interruptions but eventually began to conduct the debriefs similarly to Teacher Two. A more thorough description of the hands-on activities is provided in section of the profile of the Intern Teacher.

Teacher Two's favored mode of instruction was the use of discussion. She enjoyed having hands-on activities but assigned those activities to the Intern Teacher. Teacher Two was the person who most often conducted whole class, small group, and teacher/student dyad discussions. Her self-report that she used much questioning to gather students' understandings was borne out in her classroom practice because she continually questioned students in all discussion settings.

Instructional sequence. Teacher Two's typical teaching sequence proceeded similarly for whole group and teacher/student dyad discussions (see Figure 5). Teacher Two began each discussion with an initial Idea Invitation 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. Teacher Two 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, and (b) Activity Debrief where she held a discussion following the intern's presentation of an activity. She sometimes, but rarely, reacted to students' ideas by Showing Surprise. These strategies will be described in more detail in the following sections.

In all cases Teacher Two 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 Teacher One, 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. The elicitation and addressing of student ideas did not proceed in a cyclical

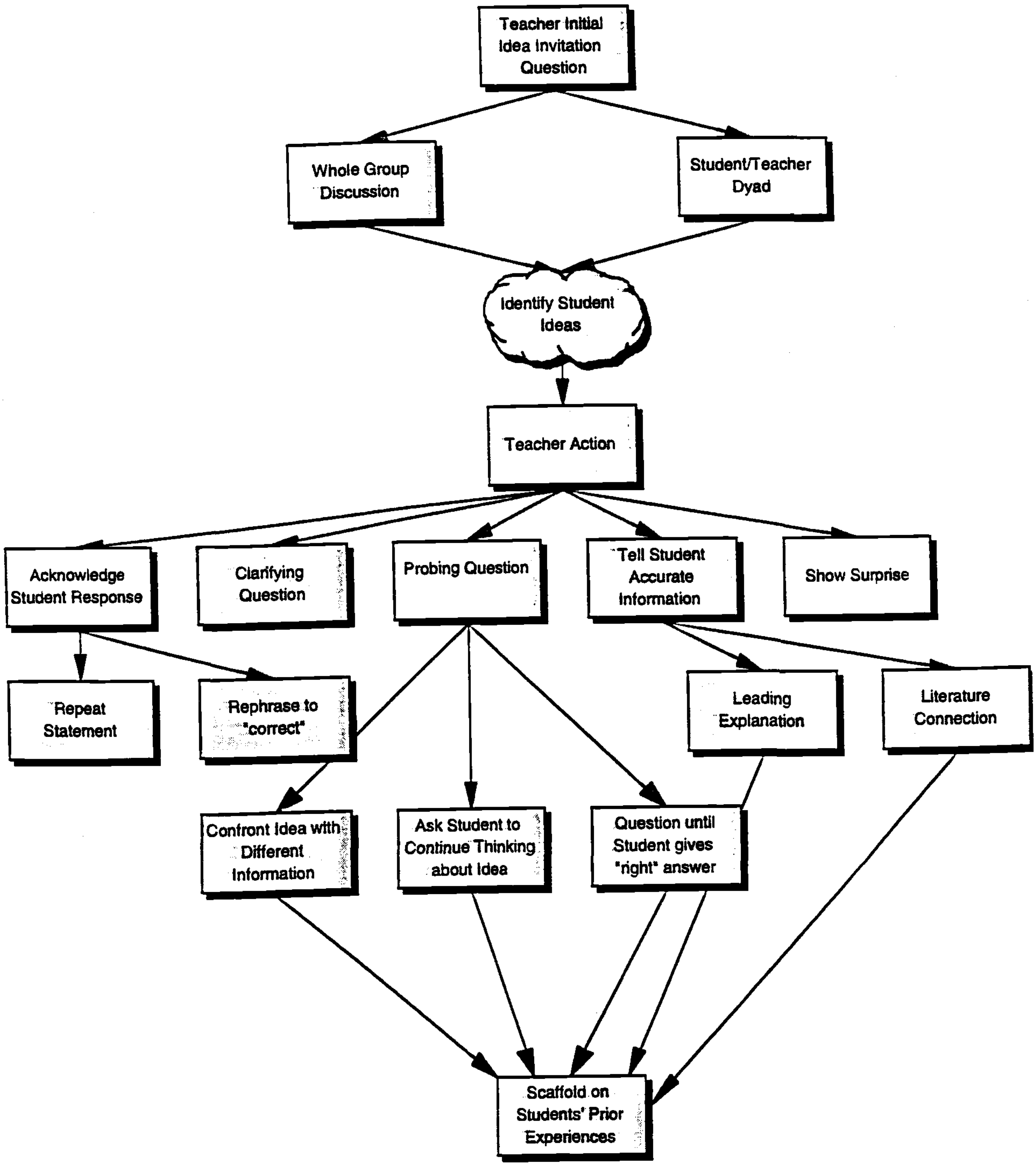

Figure 5. Instructional Sequence Teacher Two—Eliciting and Addressing Student Ideas

fashion as it did for Teacher One's class. Figure 5 illustrates the pattern of elicitation and addressing of ideas by Teacher Two that terminates without repeating. It begins again with a new idea. A more detailed description of Teacher Two's strategies of elicitation and addressing of student ideas appears in the following sections.

Teacher Two's strategies for eliciting student ideas. Teacher Two used whole class discussion as the most common mode of eliciting student ideas. She used discussion and questioning to elicit student conceptions in each lesson she led. She used an initial Idea Invitation Question at the start of each lesson. The initial lesson of the astronomy unit was a collection of student knowledge about astronomy. Teacher Two asked students what they already knew about astronomy and what they wanted to know more. She made certain each student responded to both questions by calling on non-volunteers. Teacher Two reminded the students that this talk was just a discussion to gather information about what they knew right now, and that their ideas might change when they learned more about astronomy. She asked them to discuss what they wanted to know more so she would know their interests and so they could begin thinking of a research topic. She started the discussion by prompting "We will write down what you think you know now. We might find out that some things we think right now are wrong."

During the initial lesson in which Teacher Two collected students' initial ideas about astronomy the teacher acknowledged student responses and used Probing Questions to help her understand student responses. Probing Questions were phrased in ways that allowed students to elaborate on their ideas. She did not correct student ideas, show surprise, or tell students accurate conceptions.

The following exchange illustrates how Teacher Two used Probing Questions to clarify her understandings of student thinking and to help students understand their own ideas:

> Student: Comets are destroying the moon.
> Teacher: And how is that happening?
> Student: The moon has no atmosphere so the comets are chipping parts off the moon.

By asking the student to explain his idea about how comets were destroying the moon, the teacher is finding out more about what he believes is happening. She was able to recognize that he was using a word he called "atmosphere" that was missing around the moon and allowed comets to hit the moon and chip off parts.

Teacher Two's strategies for addressing student ideas. Students in Teacher Two's classroom voluntarily expressed ideas in large and small group settings. The teacher did not discourage expression of ideas but responded in ways that showed the ideas were accepted and encouraged.

In the following exchange that occurred during a large group discussion, the teacher was initially at the voluntary statement made by the student. She later followed up on the statement with additional Probing Questions to help her understand what was being said and to help the student express her idea and the rest of the class gain an understanding of what was being said:

> Student: They got an octopus and jellyfish too…they started swimming around in space.
> Teacher: In space?…Oh my goodness! Wow! I'm amazed by that. (Very surprised.) How did they get there? (Probe for more information.)

Student: It was by the space shuttle.
Teacher: Oh—it was an experiment then do you think? (Probing for more information.)
Student: Yes.
Teacher: Oh that is so interesting. An experiment on the space shuttle.

Students often offered voluntary ideas in dyad situations. It was not unusual for them to interrupt Teacher Two during teacher/student discussions with other students. The following exchange is an example of such an interruption. The boy making the statement was recalling an experiment about gravity conducted by a guest speaker the previous day. He was relating it to information he was reading in a non-fiction children's book. Another student became involved in the discussion and questioned the first student's information. Teacher Two reinforced the voluntary expression of the idea:

Student 1: 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!
Teacher: ... How clever of you to relate that! ...you are stretching your brain.
Student 2: Yeah, but a feather would get more air to push on it!
Student 1: Yeah, but there is less air on the moon.

When a student voluntarily expressed an idea about the speed of light during a dyad discussion, Teacher Two asked a probing question to see whether the student could apply the idea to a situation:

Student: The speed of light is really fast. It is faster than sound waves.
Teacher: So which would you notice first, the thunder or the lightening?
Student: You would see the lightening first.

Teacher Two acknowledged voluntarily expressed ideas and addressed them in a variety of ways as discussed above. She encouraged expression of ideas by her acknowledgement of those ideas.

When addressing ideas that she elicited, Teacher Two used some of the same methods used for voluntary expression of ideas. However, she often used these discussions not only to collect student conceptions but to teach accurate conceptions. Upon eliciting student ideas, Teacher Two endeavored to address them using a variety of strategies such as (a) Explanation, (b) Literature Connection, and (c) Activity Debrief. She did not plan nor deliver a lesson to specifically address any ideas that were elicited or expressed during the course of the unit.

Teacher Two used a pattern during large group discussions of leading students toward the correct answer to her initial question. This Teacher-Two-strategy is termed Explanation. The purpose of this type of questioning was not only for the teacher to know what the students think but to help them develop more accurate understandings. In the interchange below the teacher probed for more information by asking, "Why is that interesting?" and then reinforced the progress toward the right response by "She is on the right track" and "You got it."

Teacher: Why is it interesting to tell us that Saturn can float?
Student: Because they can show us how it won't sink.
Teacher: But why is that an interesting thing to tell us?
Student 2: Because it might be made of something special.
Teacher: Oh—she is on the right track. Student 3, what do you think?
Student 3: It is a gas.
Teacher: You got it. It is a giant gas planet. This particular gas can float.

Like Teacher One, Teacher Two often used Literature Connection and read non-fiction children's books to her class to provide them with accurate science content. She did not have as much opportunity to read to the class as Teacher One because the Intern Teacher did most of the reading. However, while reading a book, the teacher elicited ideas the students were developing from the text by questioning them:

Teacher: (Reading non-fiction book) Anyone know why Neptune is blue?
Students: Because of the gases.
Teacher: Yes, the gases. (Continues reading.) What do you think about Pluto?
Student 1: Some scientists think that Pluto used to be one of Neptune's moons and it broke off and became a planet by itself.
Teacher: What else do you know about Pluto? Anything else you can tell us?
Student 2: That it is VERY cold… it is smaller than the Earth.
Teacher: Okay. (Continues reading). Is there anything past Pluto? Any other planets?
Student 3: Well, I saw on the news there might be something past it, like it could be a star, or a moon, or another planet, but we don't know for sure yet.
Teacher: They are still researching it and thinking about it.

Though Teacher Two did not teach the activities herself, she did make suggestions to the Intern Teacher of which activities to present to the students. Teacher Two circulated among the students when she was present while they were engaged in the activity presented by the Intern Teacher. Teacher Two often joined in the debriefing of the activity lessons, using an Activity Debrief Strategy by asking questions and raising points to help students think about the activity. The following passage illustrates a discussion led by Teacher One after an activity delivered by the Intern Teacher. The objective of the Intern's activity was to illustrate to students the difficulty astronauts have in manipulating items while wearing thick, insulated gloves.

Teacher: I had people tell me you would keep oxygen in your gloves. Why would you want to keep oxygen in your gloves? Is there something you were thinking about?
Student 1: All of your body needs oxygen, you don't just need it to breathe.

Teacher Two used the discussion above as a segue to provide information that she found about the Hubble telescope to students. She then asked students to problem solve ways to fix the Hubble telescope:

Teacher: They are trying to get the Hubble fixed because it is having problems. They want it to last five months, and if they don't get it fixed it will last only half the time. What could they do, what are some possible things they could do to get it fixed?
Student 2: They could see things in space with it.
Teacher: That is what they could use a telescope for, but if it isn't working, what could they do to make it work?
Student 3: If they had another one they could send one up, or they could bring the other one back and fix it.
Student 4: Maybe they could find a spaceship with a crew in it to fix it.
Student 5: I think that whatever part is missing, they could trade the parts by carrying it in the space shuttle.
Student 6: They could take the other one down to Earth and work on it, and maybe build another one.

It seemed the discussion was off the topic of using gloves in space, but Teacher Two connected the interchange back to using gloves in space in the exchange below. She focused the lesson away from the purposes of gloves in space to friction and movement under weightless conditions:

Teacher: Actually, they have already worked on the Hubble telescope....They actually trained crews to go up there with robotic crews. So would they need these kinds of gloves to work on the telescope?
Students: Yeah!

Teacher: Now you have some ideas of what would be helpful to have on your gloves—friction would be helpful to help you hang on to things. How could you keep your things from floating away?
Student 7: Use Velcro.
Student 8: You could have a kind of a cord that is hooked on to your tools and it is hooked on to you so it won't go away.
Student 9: You could have lots of pockets and stuff to carry things in.
Teacher: All these things had to have someone thinking about them and saying, "this would be a good idea."
Student 10: Maybe magnets would work.
Teacher: These are areas you might think about in your futures—you may have to use some of these things if you get a job in space. I'm glad I got to talk to you because it was most interesting.

Teacher Two held a concluding discussion to discern the development of student ideas toward accurate conceptions. The students were gathered at the front of the room and the original chart of questions from the beginning of the unit was hanging in the front. The teacher read each question, and students were asked to respond to those questions. The students' report booklet was used as a resource for answering the questions. Teacher Two held students more accountable for accurate responses during this lesson than during the initial collection of ideas. She encouraged students to respond to the questions thinking about the physics involved and without relating their responses to personal needs. In the exchange below she focused the students away from thinking the Earth spins for the good of humans. However, in addition to using poor questions to elicit student ideas, it is probable she did not know enough science to direct the discussion adequately and let the topic drop.

Teacher: Why does the Earth spin around? Who has an idea about that?
Student 1: Because if the sun just stays in one place all day then some people would just have to sleep all day because it wouldn't be night.
Teacher: Well, it is a good thing the Earth spins, but why does it spin?

Student 2: So that it will be day and night, and plants can grow.
Teacher: It is a good thing the Earth spins for those reasons, but what makes it do that?...(She begins spinning the globe beside her). I'd better keep this spinning so people can have day and night?
Student 3: It has something to do with the sun's gravity. And also the moon's gravity, since it is strong enough to make the tides maybe it is strong enough to help pull the Earth around.
Teacher: So you think there is a relationship between gravity and what happens with the Earth? That is an interesting thought. (Teacher drops the line of discussion.)

Teacher Two allowed for differences in opinion when there was not a clear answer to the questions raised. The interchange below shows the openness to ideas even at the conclusion of the unit. Teacher Two addressed the ideas by paraphrasing student responses, encouraging them to think about possibilities and to share their thoughts:

Teacher: Are there aliens in space?
Student 1: We haven't really found that out. Maybe there are.
Student 2: Well, maybe in another galaxy. Not like here.
Teacher: It may be possible in another galaxy, but not that we know of today?
Student 3: Maybe. Because we don't really know.
Student 4: Probably because space is really big, and if there was only life on one planet on one galaxy then it would be weird.
Teacher: So there is so much out there that it would seem odd if there weren't life in more than one place? Okay.

Teacher Two used discussion strategies in the form of Leading Explanations, Literature Connections, and Activity Debriefs when addressing student ideas. She used no demonstrations or manipulatives with her instruction. She planned no lessons to specifically address student ideas. However, the description in this section of Teacher Two's strategies does not address all areas of instruction in Classroom Two. The Intern Teacher delivered much instruction in this classroom. The Intern Teacher delivered all of the hands-on instruction. It is not certain whether Teacher Two would have provided the number of activities that were taught were the Intern not in the classroom. In fact, Teacher Two stated that many of the activities were new this year, and she was delighted the Intern was there to teach them and do the time-consuming preparation for the activities. In any case, it is certain the Intern Teacher did impact instruction and student outcomes in Classroom Two. Because her instruction undoubtedly impacted student outcomes in Classroom Two, her profile is presented before the discussion of student knowledge in the Classroom.

Intern Teacher

The Intern Teacher was working toward a Master of Arts in Teaching (M. A. T.) in Elementary Education degree. Her internship in Classroom Two played a major role in obtaining her degree. She holds a Bachelor of Arts (B. A.) degree in Liberal Studies. The only teaching she has ever done has been as an intern, and the only science she has ever taught was in this second grade classroom. She recently took and received an "A" in a college astronomy course at the same university at which she was earning her Master's degree. She was amazed that she had received an "A" in astronomy because she did not believe she learned very much. At the post-instruction interview her content knowledge seemed much stronger than at her pre-instruction interview. It appeared she was reminded of information that she had previously learned through her own delivery of content. She became quite excited about astronomy even intending to teach it in her own classroom.

<u>Content Knowledge</u>

True to the Intern Teacher's perception of her knowledge, her pre-instruction content knowledge was not strong. She was hesitant about her responses and concerned that she appeared not to know much. She was present during Teacher Two's pre-instruction interview and may have been influenced in her responses by knowledge of questions that would be asked. Some of her responses seemed stronger than they would have been had she not studied the topic in preparation shortly before her interview.

The protocol began with questions about science content based on teacher goals. The teacher goals included understanding a definition for astronomy, knowing careers related to astronomy, and the ability to name and draw the nine planets in order from the sun. The Intern Teacher defined astronomy as a study of space and everything in space. She included in her definition "everything involved with space." She thought students should know about the astronaut as a career option but wanted them to know of other support careers such as geologists, engineers, and physicists who work in careers related to astronomy. She correctly named all the planets in order of distance from the sun.

Subsequent questions were developed from the *Benchmarks* for K-2 students to know about astronomy by the end of second grade. The Intern Teacher believed the Earth was spherical and that gravity keeps us on the Earth. She believed that gravity pushed from above us in the atmosphere to hold all objects on the Earth. This conception was apparent in her lessons when she taught students that gravity pushed down from above us.

When selecting balls to represent the sun, moon, and Earth, the Intern Teacher chose relative size as the criterion. She discussed the movement of the three in a traditional fashion, stating that the Earth and the moon spin on their axes, and that the

Earth orbits the sun with the moon orbiting it. She was certain the sun did not spin but was positive the Earth and moon rotated in a counterclockwise clockwise direction because she had seen it on *Bill Nye the Science Guy*.

The Intern Teacher believed the moon does not always look the same in the sky. She studied this topic prior to the interview in preparation for her lesson. She described the perceived changes in terms of phases of the moon. She stated the moon looked different because the sun reflects only on part of the moon and depending on where the Earth is in relation to the sun and moon we see only part of the reflected portion. She recognized that it took about a month for the moon to proceed through a cycle of first appearing to grow larger and then appearing to become smaller. She drew her representations to reflect that cycle (see Figure 6).

The Intern Teacher believed there is a countless number of stars. She stated there were simply too many to count. She believed that stars are made of gas, explicitly stating it was hydrogen gas that caused explosions on the sun. She agreed that stars were circular. She agreed that people probably draw the points to represent solar flares coming off the balls of gas.

The Intern Teacher chose to respond to the final question and share whatever she wanted about astronomy. It is interesting to note that like Teachers One and Two, the Intern Teacher responded in relation to teaching about astronomy to children. She stated that astronomy was "hard to teach" but that it is important to teach about astronomers and what they do.

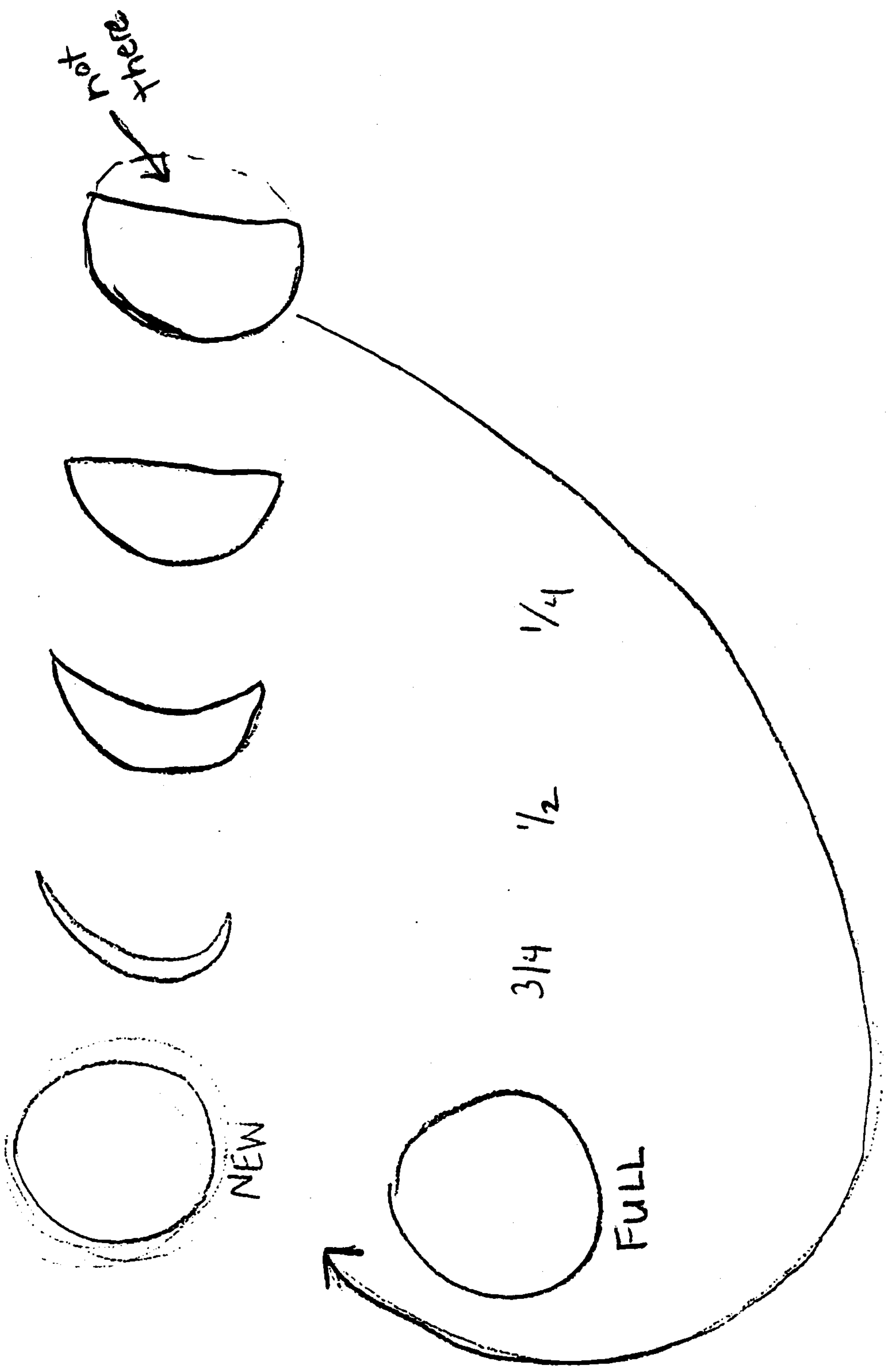

Figure 6. Intern Teacher's illustration of the phases of the moon.

Beliefs about Science Teaching and the Importance of Children's Ideas

The Intern Teacher believed the most important consideration for teaching science was to make it age appropriate and concrete as possible. She believed many of the astronomy concepts were abstract, and needed much in the way of visual representation to make them accessible to children. While the intern believed science was important in primary classrooms, she did not believe it should be the major emphasis. She believed it was more important to teach reading and writing, and thought "it will be easier to do science when you know how to read and write."

She had the perception that knowing what students think about science concepts was important. Her view of discussions as a way to identify their understandings was similar to that of Teacher One and Teacher Two:

> If we had all the time in the world I think student interviews would work because … we would know what they understood. By talking to them they can verbalize their understandings…Drawing is another way to get what they know, and then the teacher …having students dictate sentences that go with their pictures.

Having no previous experience teaching astronomy to second graders, the Intern Teacher did not have any ideas of common conceptions students of that age would have about astronomy. She did have a perception that students would not have accurate conceptions, and that some of the students' ideas would be false. She believed most of the inaccurate conceptions would have developed from their exposure to the media:

> Some students think of weird information. Right now some students still think there are aliens...You have to talk about it… say there might be aliens, but we don't know. I think some things they come in with are from

the media and TV... Kids know there is a sun and a moon, but they don't pay much attention to how they work in the sky.

Thus, the Intern Teacher did have some prior beliefs about student knowledge influencing their learning and even her own teaching. She did not discuss students coming to erroneous ideas from their past experiences but through sources like the media. This final statement about children not paying much attention to how the sun and moon work in the sky may be inaccurate because children do pay attention to the sky, and do develop conceptions of how they "work in the sky."

Classroom Practices

Science was taught in Classroom Two on a daily basis. The Intern Teacher presented all hands-on activities during the unit. Teacher Two told the Intern Teacher the concepts she wanted addressed. The Intern Teacher found the 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.

The Intern Teacher also taught art and language arts lessons during the given daily time period on occasion. Students wrote stories about themselves in space, created crayon reliefs of space scenes, painted pictures of the moon, and designed aliens to live on various planets.

Instructional sequence. The Intern Teacher's typical teaching sequence consisted of an initial Idea Invitation Question that was presented to the whole group. Students readily responded to the prompt. Occasionally the Intern Teacher was unsure of how to respond to the students' statements and seemed surprised at their statements. Greater detail about her difficulty in responding to students is given in subsequent sections.

Following the initial discussion, the Intern 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 the Intern circulated through the room, keeping students on task and verifying they were following procedures.

Following the activity the Intern Teacher asked students to meet together as a whole class group to discuss their findings from the activity. The Intern always asked the students "Why do you think we did this activity?" and "What did you learn from this activity?" Students always responded to her queries. The Intern Teacher 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, the Intern Teacher believed it was her questioning skills that prompted unusual student responses. She rephrased her questions to make them more understandable to the students. Occasionally she ignored students' responses, and sometimes she continued her questioning until she obtained the "correct" response. More detail regarding how the Intern Teacher elicited and addressed student ideas are discussed in the sections below.

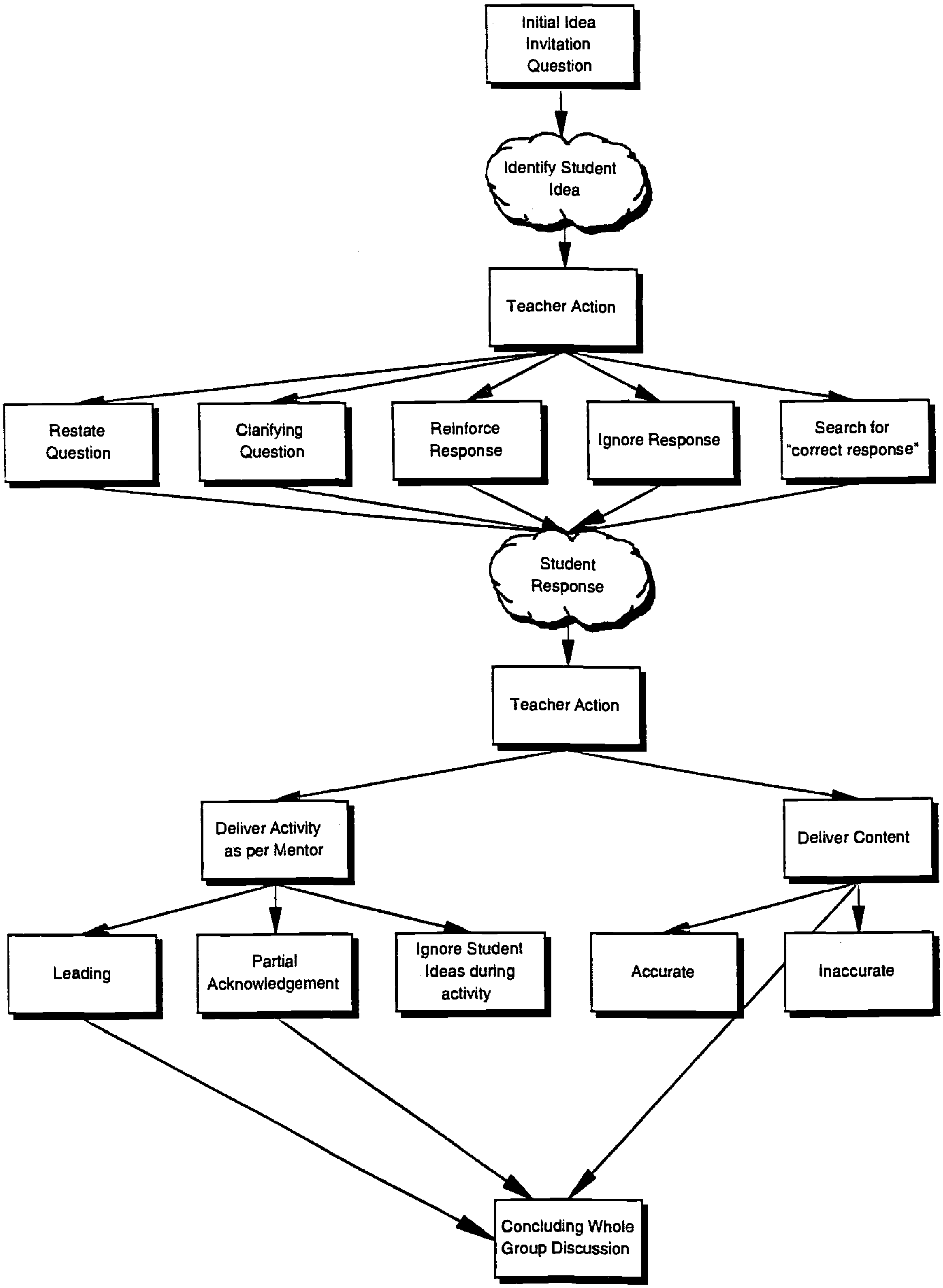

Figure 7. Sequence of Instruction, Intern Teacher—Eliciting and Addressing Student Ideas

The Intern Teacher's strategies for eliciting student ideas.The Intern Teacher elicited student ideas through initial Idea Invitation Questions prior to activities. Figure 7 illustrates the Intern Teacher's pattern of instruction and elicitation and addressing of student ideas. All elicitation of ideas took place in the large group setting. She did not solicit ideas in small groups or in teacher/student dyads.

The Intern Teacher sometimes elicited ideas by showing visual aids such as photographs in books or posters as prompts for student ideas. She used them as invitations to start discussions about whatever concept she would be presenting. She used a photograph of an astronaut in a spacesuit to start a discussion about why astronauts' suits are so bulky. The discussion led to the activity where students manipulated objects while wearing oversized gloves. Given her statement about astronauts feeling hot or cold on planets it seemed she thought they traveled to different planets indicating a faulty understanding of content by the Intern Teacher.

Teacher: Look at the picture of the spacesuit. It looks kind of puffy, doesn't it? Does anyone know why it looks kind of puffy?
Student1: It is cold in space.
Student2: They have to keep their hands warm. It has stuff in it to make them warm.
Teacher: If they had regular gloves they would get hot on hot planets and cold on cold planets. What would happen to the oxygen if they didn't have any gloves on?
Students: Die.
Teacher: No, what would happen to the oxygen.
Students: It would escape.
Teacher: Right, and then they would be in trouble. When they are in the spacecraft they don't have to wear the gloves. We are going to use some adult size gloves on your small hands so you can see what it might be like to try to do things with space gloves on.

The above use of a visual aid to elicit student ideas was not effective for the Intern teacher. She was not willing to accept student ideas as they were expressed but rather focused them on other ideas. She was more concerned with getting to the activity then knowing student understandings.

The Intern Teacher more commonly elicited ideas through initial Idea Invitation Questions prior to activities. The following shows her initial Idea Invitation when studying rockets:

> Teacher: Who knows how rocket ships fly? Raise your hand if you know how it flies. (Many hands go up.) Okay. What we are going to do is make a list. We are going to see if we can list ideas about how we think it can fly. Because it just doesn't go up on its own.

She recorded student responses on chart paper and accepted all ideas. She did not elicit student ideas in small group or dyad situations. She had students record their ideas and inferences on record sheets following investigations. An example of a student's written record is in Figure 8. The drawing represents the student's understanding of the relationship of the Earth, moon, and sun in the sky, and how they move.

The Intern Teacher's strategies for addressing student ideas. Students in Classroom Two were accustomed to voluntarily expressing their ideas in their classroom. The Intern Teacher was often unprepared for their ideas and surprised to hear some of their ideas.

In the exchange below students were acting in roles as the Earth, moon, and sun. Three students were demonstrating how to act the roles of the sun

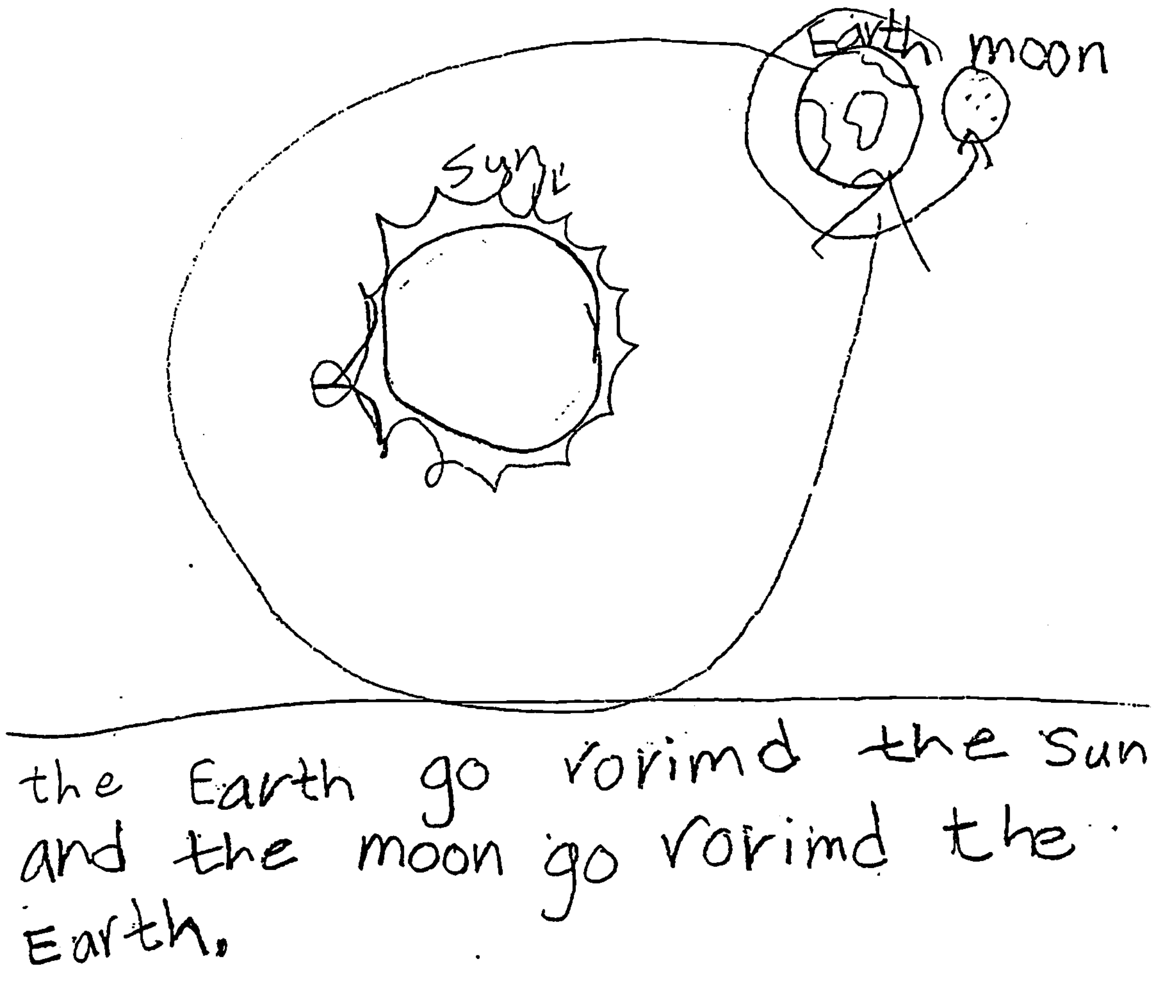

Figure 8. Student recording of conception of relationship of Earth, moon, and sun, and their movements in space.

a remaining fixed in the center, the moon rotating and revolving around the Earth as it was rotating and revolving round the sun. All students eventually played all roles. During the demonstration Student 1 expressed his idea of why we are able to see only one side of the moon. He strongly believed the moon did not rotate, and in fact, told this belief to the researcher in the pre-instruction interview. His idea became public in class in the interchange below:

Teacher: It spins too. So now it spins around the Earth, and the Earth moves, and everything goes around the sun. (Student 1, playing the part of the sun, is raising his hand.)
Student 1: Wait, the moon doesn't spin or we would see the back of it sometimes.

Teacher: Okay. Maybe we can stop and talk about this. Student 1 just said that the moon must not spin because we never see the back of it. Well, the moon rotates the same as the Earth does, and somehow the way we see it, it is always going to be the same side. We are always going to see the same side of the moon. How many hours does it take for the Earth to turn completely around?
Student 2: 24
Teacher: 24. If the moon is rotating and you always see the same side, how many hours do you think it takes?
Student 3: 24
Teacher: 24, right. How long does it take for the Earth to get all the way around the sun?
Students: A year.
Teacher: How many days is that?
Students: 365.

During the interchange, the Intern Teacher endeavored to help the students to see that it was the way and the timing of the moon's rotation in relation to the Earth's that was reason only one side of the moon was visible. However, the information she led the students to understand was inaccurate. She should have explained to them that the moon makes one revolution every 28 days, which is the same as one of its orbits. That is why only one side of the moon is visible. In addition, following up with an exchange regarding the length of a year did not lead to an understanding of why just one side of the moon is visible. She could have had students role play the moon and the Earth to be able to visualize her explanation.

The exchange below provides further evidence that the Intern Teacher did not always know how to react to student ideas. The discussion took place following an activity designed to help students understand how the moon got craters. Students dropped different sizes of marbles, rocks, and shells into a pie pan of flour. The rocks, marbles, and shells represented meteorites. The students watched to see the indentations made in the flour. The indentations represented craters. The students measured the lengths of the indentations and made drawings of their observations. The exchange took place after a student mentioned that the small marble went deeper into the flour than the larger marble of the same material. The Intern Teacher did not seem to have enough knowledge of why the smaller marble may have gone deeper or even to ask the students to consider factors other than weight that could have contributed to the difference.

> Teacher: I think Student 1 had a really good thought though, if it is smaller it could go deeper. Right?
> Student 2: That is because it is lighter.
> Teacher: It is lighter... We have to try that out again maybe some time. Any other comments before we stop?

She generally responded in ways that discouraged expression of ideas, using strategies of Leading, Partial Acknowledgement, and Ignoring that enabled her to keep on the track of presenting the information she believed she needed to cover. It was not unusual to find the students changing their responses to the Intern Teacher's questions based on her responses to their answers. Instead of probing for reasoning behind student responses, the Intern Teacher sometimes addressed student responses by using a Leading Strategy that consisted of repeating them in a question form that lead students to restate their response with the opposite reply. The exchange below, during a discussion about how rockets propel into space, illustrates the change in student response following such a question by the Intern Teacher:

> Teacher: Is the fire pushing down or up?
> Students: Up.
> Teacher: The fire is pushing up?
> Students: Down.

When the Intern Teacher wanted to focus on only part of a student's response to encourage a certain line of thinking, she used a Partial Acknowledgement Strategy. This strategy focused on acknowledging only the portions of a child's statement that helped the Intern direct the lesson in the way that she wanted. She conducted a lesson on Newton's Third Law. The lesson was developmentally beyond the level of the second graders, particularly the terminology. The Intern Teacher tried to connect it to their experiences with swings but could not effectively do so. When Student 1 expressed her idea of what happened with a swing, the Intern Teacher focused only on the first part of the student's response. The Intern Teacher tried to explain Newton's Law with the drawing but was not able to get the scientific information across to the students. Student 2 took the line of reasoning into a different direction when he discussed the swing as being attached to the bar of the swingset. The swing was probably not an appropriate example of the law because, as every second grader knows, when a swing is pushed it does go back and forth and does not immediately go back to its resting point, as the Intern Teacher had drawn on the board:

> Teacher: When Newton was talking about every time there is an action there is a reaction. When you push the swing that is an action. What is the reaction?
> Student 1: It goes back and forth.
> Teacher: It goes back. (Ignores student's full response.) Let's draw a little picture. Here is a swing. Let's say you push it this way, it goes back to look like this at its first place. ...it will go up, and when it goes back it is the reaction.
> Student 2: Yeah, because the metal bar holds it so it doesn't come off. If you pushed it and it wasn't stuck it wouldn't ever come back.

An example of the Intern Teacher using an Ignoring Strategy to redirect a student response is in the interchange below. The class discussion surrounded an activity to plan balanced meals for the astronauts to take with them to space. When Student 1 responded with an idea of what the astronauts could drink, the Intern Teacher did not include the word "mineral" but was insistent on listing only water, and then only with another beverage included in the menu. Earlier in the same lesson another student suggested sourdough toast as a breakfast food and the Intern Teacher listed only "toast."

> Teacher: Now we need something to drink.
> Student 1: Mineral water.
> Teacher: We already have water.
> Student 1: Mineral water. It has sort of a lemon, lime, or raspberry flavor to it.
> Teacher: We'll have water as an option, but what else could we have? I think we need another dairy.
> Student 2: Milk.

The Intern Teacher accurately perceived that, at the conclusion of the unit, many students did not have a correct conception of the definition of astronomy. In this case, she chose to address their ideas by holding a class discussion that she hoped would help them to grasp an accurate definition of astronomy. In the exchange below she began by asking for student ideas about astronomy and then asked students to clarify their definition by presenting examples of things that may be studied to see whether that would fit student definitions for astronomy.

Teacher: I would like to know what is astronomy. If you have a definition, raise your hand. We have been studying it for three months, so what is it?
Student 1: It is studying things, like caterpillars.
Student 2: It is space.
Teacher: What have we been learning when we say it is time to study our astronomy?
Student 3: Learning about planets, stars, galaxies.
Teacher: It is the study of space.
Student 4: Study of space, and our hurricanes. And our weather.
Teacher: Is that a study of space? So if I said a study of animals, would that be the study of space?
Students: NO!
Teacher: What about study of ice cream?
Students: NO!

Following the interchange above, the Intern Teacher presented students with a dictionary definition of astronomy. She then provided students with examples of terrestrial and extra-terrestrial items and asked them to decide whether or not these examples would be considered part of a study of astronomy. It is apparent that generally the Intern Teacher responded to student ideas in ways that discouraged their expression.

The following section provides a discussion of student knowledge in related to the practice of Teacher Two and the Intern Teacher. A change in student knowledge over the course of the unit is described.

Student Knowledge

To track teacher effects on learning outcomes, student content knowledge determined by interviews was assessed pre- and post-instruction. Prior to instruction 10 students from each classroom were selected by each teacher to participate in pre- and post-instruction interview designed to assess student knowledge. A more detailed description of teacher and *Benchmarks* (1993) goals is given in Appendix B. A comparison made of pre- and post-instruction interviews enabled a determination to be made about the success of each teacher at helping students attain both teacher and *Benchmarks* (1993) objectives. Teacher goals were for students to know:

- A definition for astronomy
- Astronomy-related vocations
- The names of the planets in order from the sun
- The relationship of the Earth, moon, and sun.

The *Benchmarks* (1993) goals were for students to know:

- The moon looks a little different every day, but looks the same again about every four weeks.
- The sun can be seen only in the daytime, but the moon can be seen sometimes at night and sometimes during the day
- There are more stars in the sky than anyone can easily count, but they are not scattered evenly, nor are they all the same in brightness and color.
- The sun, moon, and stars appear to move slowly across the sky

Knowledge change in Classroom Two was dependent on Teacher Two and the Intern Teacher actions. As described above, Teacher Two orchestrated most of the class discussions, including debriefs of the activities presented by the Intern Teacher. The Intern Teacher presented all the hands-on activities in the class. Teacher Two gave the topics she taught to her, but she developed and presented them independently.

Prior to studying the unit, only six students in Classroom Two had a conception of what "astronomy" meant. Students continued to lack a definition until the Intern Teacher presented a lesson on the final day of the unit during which students were asked to define and apply the definition. All students understood that astronomy was the study of "stuff in space" at the conclusion of the unit. Each student was able to draw and name all the planets in order from the sun at the post-instruction interview.

Students did improve in their understandings of gravity, though four students believed gravity "pushed on you" from the air above. The Intern Teacher told students this idea several times during her instruction. Teacher Two did not address the concept of gravity with the class, but a guest speaker presented an activity designed to help students understand that air resistance affected how objects fell to the Earth, not the mass. Only three students understood that gravity pulled toward the center of the Earth at the conclusion of the unit. The other seven interviewed believed that objects were pulled toward the bottom of the Earth.

Students had better understandings of the relationship of the Earth, moon, and sun at the post-instruction interview. All students used relative size as the criterion for selecting balls to represent the bodies. Only seven students used this criterion at the pre-instruction interview. Students understood that the Earth spins and revolves around the sun, with the moon spinning and revolving around the Earth. The Intern Teacher presented a lesson where students acted in the roles of the Earth, moon, and sun, and then drew representations on paper of what they had acted and their new understandings. Teacher Two was not involved in this particular activity, not even at the debriefing stage because it was during the Intern Teacher's solo weeks of teaching.

Students in Classroom Two had a better understanding at the post-instruction interview of why the moon looks differently in the sky. Seven students understood it had something to do with the reflection of light from the sun and the "way the moon and Earth were in the sky." Teacher Two assigned homework to the students to track the way the moon looked in the sky each night and held discussions nearly every day to allow students to describe the differences they saw. Thus, the idea of the apparent changes in the moon was revisited many times during the unit. Students recognized the changes occurred in a certain order. In addition, the Intern Teacher delivered a lesson during which students participated as the Earth and parts of the moon's orbit so they could see that the positions of the moon and sun in space affected which part of the moon one could see "lit up" on the Earth. The conceptions represented a significant change from the pre-instruction responses where five students believed something like clouds, other planets, or even the sun, covered the moon, causing it to look different.

Only three students responded to the final question asking them to tell anything more about astronomy they wanted. These students responded with factual information they had gathered from studying their individual topics. Student knowledge seemed to improve but to a lesser degree than students in Classroom One. The greatest area of improvement were the conceptions of what caused the moon to look different.

Classroom Two Summary

Both Teacher Two and the Intern Teacher played major instructional roles in Classroom Two. Teacher Two conducted much of the discussion and debriefings of activities. The Intern Teacher delivered all of the hands-on activities. Because the instruction in Classroom Two was shared between the Intern Teacher and Teacher Two, it is not possible to separate their effects on student learning. Thus, both teacher practices are included in the section on effect on student learning.

Teacher Two summary. Teacher Two had a background that can be considered to be typical of most elementary teachers. She was an early childhood specialist with a strong interest in literacy and teaching language arts. She saw science as serving an important role in the primary classroom. She believed science could help students maintain their interest in learning.

Teacher Two did not have a high level of knowledge of astronomy. She was unable to accurately answer all questions related to even the teacher goals for students to attain. She had some faulty, along with some accurate, conceptions of *Benchmarks* (1993) goals for K-2 astronomy. For instance, she did not discuss her ideas about gravity, but knew it would pull things that were dropped toward the center of the Earth. She believed if the sun exploded parts of it would go throughout the galaxy and believed this would be how students would respond.

Children's ideas in science seemed to influence Teacher Two. She recognized students would have understandings of concepts prior to instruction, and she noted those understandings would have components of persistence, coherence, structure, and perceptual dominance that are qualities of children's ideas as defined in the research literature. Teacher Two approached her science instruction similarly for large and small groups. She was motivated to know student ideas and used an Idea Invitation question and accepted student responses in small and large group settings. She used Probing Questions to clarify and gain understanding of the depth of those ideas. She reassured students that she was interested in their ideas and not scientific knowledge.

Student ideas also influenced Teacher Two to develop strategies to address those ideas. She used a variety of different strategies, such as Literature Connection, Explanation, or Activity Debrief to address student ideas. The Activity Debrief allowed Teacher Two to address student ideas following an activity presented by the Intern Teacher.

Intern Teacher summary. As is typical for any teacher intern, the Intern Teacher had little experience teaching elementary science subjects. The astronomy unit she was co-teaching in Classroom Two was the first elementary science she had taught. She had, however, recently completed a college-level astronomy course in conjunction with her M.A.T. degree. She received an "A" in the astronomy course. Though she had successfully taken the astronomy course, her knowledge of astronomy was not strong. The Intern Teacher studied concepts prior to teaching them, which helped her increase her own content knowledge.

The Intern Teacher believed teaching science in primary grades was important, and that it needed to be age appropriate and concrete. She thought that interviewing students for their ideas would be a good way to understand what they think but recognized that was not possible in classroom practice. She knew students would have faulty understandings about astronomy concepts, but did not recognize that those understandings could come from experience, but, rather, believed they came from things they saw and heard through media such as television. Her interpretation of student ideas did not mesh with the definition given in the research literature that includes components of coherence, persistence, structure, and perceptual dominance.

Student ideas did influence the Intern Teacher. She endeavored to "know" their ideas through Idea Invitation Questions at the beginning of each lesson. However, she did not expect their responses to be so unconventional and attributed them to her own weak questioning ability. She did not use Probing Questions to follow up on student ideas and did not elicit ideas in small group or dyad settings. Though she elicited student ideas, she did not address them in ways that encouraged continual expression of ideas. She was influenced to develop strategies that eliminated student expression of ideas that seemed off the topic and inhibited how she was able to cover her lessons. The Intern Teacher was not successful in addressing student ideas. Generally, she did not recognize student ideas, and thus, did not address them in ways that allowed children to adapt their views. To try to get the type of responses she thought she should get she used several strategies. She used Leading, Partial Acknowledgement, and Ignoring, all of which discouraged children from sharing their ideas and from her in taking them into account.

Effect on student learning. While Teacher Two recognized and encouraged expression of ideas, the Intern Teacher did not recognize student ideas and actually discouraged their expression. Students in Classroom Two were less willing to share their ideas at the post-instruction interview. In addition, though their content knowledge did improve over the course of the unit, it did not improve to the level of the students in Classroom One. Certainly an influence on their content knowledge is the knowledge of the teachers. Both Teacher Two and the Intern Teacher demonstrated difficulty in organizing responses for students. Teacher Two attempted to orchestrate discussions around scientific concepts but was unable to follow through on all ideas because of her limited knowledge. Both Teacher Two and the Intern Teacher had difficulty responding to interview questions and expressed concern with their own knowledge. However, another influence on student knowledge is certainly that their ideas were not taken seriously during the time the Intern Teacher was in control of instruction. Also Teacher Two was limited in how she could address their ideas by the fact that the Intern Teacher was delivering so many lessons, and of course, her own knowledge of astronomy.

Elicitation of Ideas—Were Student Ideas Always Expressed in the Classroom Settings?

Teachers said they elicited student ideas to understand student conceptions about astronomy. Teachers used discussions to elicit thinking as ways of assessing student understanding and learning and to plan future lessons. Their focus was on knowing student conceptions to help them find a starting point for instruction. The current study focused on noting how classroom teachers elicited student ideas. Clinical interviews were conducted to understand student pre- and post-instruction knowledge of astronomy. The clinical interviews allowed the researcher to make comparisons of when and whether the same student ideas were expressed in the classroom as in the interview setting. It was apparent that many, but not all, student ideas elicited in the clinical interview became known in the classroom setting. Examples of ideas expressed and ideas that were not expressed in the classroom are provided through a discussion regarding the relation to student learning. In this statement, the student told the researcher in an interview setting that he believed the moon did not spin, and why he believed that:

> Student: ...The earth turns around and around the sun. And it spins, too. It is also turned like this [tilted]. The sun stays in one spot. The moon goes around the earth. It orbits around the earth. It doesn't spin. That's why we always see the same side.

His viewpoint (that the moon did not spin, and thus only one side would be visible), became public during a classroom discussion by the Intern Teacher in Classroom Two. He voluntarily expressed his idea during an activity that illustrated the movement of the Earth, moon and sun:

> Teacher: Is that all the moon does?
> Student 1: No, it spins.
> Teacher: It spins too. So now it spins around the Earth, and the Earth moves, and everything goes around the sun. (Student 2, playing the role of the sun, is raising his hand.)
> Student 2: Wait, the moon doesn't spin or we would see the back of it sometimes.
> Teacher: Okay. Maybe we can stop and talk about this. Student 2 just said that the moon must not spin because we never see the back of it. Well, the moon rotates the same as the Earth does, and somehow the way we see it, it is always going to be the same side. We are always going to see the same side of the moon.

The student who voluntarily expressed his idea was able to make it known in public and to receive an explanation. The student who made his ideas public was forceful, thoughtful, and always raising his hand. He was of the personality to discuss his ideas and concepts being taught in class. He had the reputation of being one of the "smart kids" according to the other students, Teacher Two, and the Intern Teacher.

The following student had a different experience. She tried to make her ideas public in class; also through a voluntary expression, she was not successful. She lacked confidence, was timid and spoke softly. She was also a student in Classroom Two. In the interview excerpt below, she told the researcher her classification system of stars:

> Interviewer: Tell me what you know about stars.
> Student: (Doesn't answer the question. Immediately begins drawing and coloring stars—five pointed stars.)
> Interviewer: Do stars always look like that?
> Student: Not really. That is a wishing star. Some stars are shooting stars. I don't know why some stars are shooting stars. I'm going to draw a big wishing star. (She then drew more stars, colored them bright yellow and labeled them "regular stars," "shooting stars," and "wishing stars." She was not able to differentiate between the stars, nor why she thought there were three different kinds of stars.)

In the exchange below the student initiated sharing her idea publicly but did not follow up when the teacher did not hear her. The student did not repeat her statement:

> Teacher: We are missing some stars. So I have some different kind of stars we can make...Now, in outer space stars don't really look like these, right? They look like our sun…
> Student 1: (Spoken very quietly.) They are wishing stars.
> Teacher: What?
> Student 1: Never mind.
> Teacher: Okay.

She had a reputation of being a less serious student and from observation it appeared she did not often respond to teacher queries. Her idea did not become publicly known in the classroom, but the previous student's idea did. In each instance the students were voluntarily sharing their ideas but the response to each was different. At the post-instruction interview the first student understood that the moon did spin on its axis, though he initially responded with his original idea:

> Student 1: The moon doesn't spin. The moon goes around the Earth, the Earth goes around the sun and it also spins. I know the moon doesn't spin because we never see the other side of the moon. Actually, it does spin. Because I read in a book. We only see one side because it spins the same pace as the Earth does, so we only see one side. (Uses ball to demonstrate.) If we lived on this side, see, the moon spins the same way, so see, only one side shows to the Earth.

This student did gain a more accurate conception of the movement of the moon because he now recognized that the moon did spin. He did not have a completely scientific explanation, but his idea was more accurate. He received an explanation for his idea by the Intern Teacher and claimed to have read about it in a book. The student with the misconception about the stars did not make growth in her understanding about the shape of stars. Neither Teacher Two nor the Intern Teacher were aware of her idea and did not address it in instruction. At the post-instruction interview it became apparent that the student continued to hold the belief that stars had five points and there were three kinds of stars, regular, wishing, and shooting stars:

> Student: A shooting star is when is star is like right here and it shoots across the sky. So it is a special star. A wishing star is a special star, too. But a regular star is just a regular star. (Draws all stars to look the same, but the shooting star has a tail.)

Thus, the student whose idea became known in the classroom progressed toward a more accurate understanding of the concept than the student whose idea did not become known in the classroom. Teachers were able to address the first student's idea because they were aware of it. In the case of the student whose idea was not known, the teachers were not able to address the conception. There is, of course, no guarantee they would choose to address the idea had they known of it, particularly because this student was the only one who expressed the idea. Given this idea was not an idea they expected to identify, and it is an idea of which they were unaware; it is not surprising they did not spontaneously address such a concept.

Teaching for Conceptual Change

Given the nature of the teachers' interpretations of student ideas and their strategies for science teaching, are they engaging in conceptual change teaching? Previous research has focused more on describing student change in ideas relative to strategies given teachers by researchers and less on actual teaching practice relative to conceptual change. It has been a difficulty finding a description of actual teaching practice in the primary grades relative to eliciting and addressing student ideas. In order to focus attention on teaching practices, Teachers' practices in this study were held to the criteria based on the following guidelines for changing children's ideas in Osborne (1985):

1. Take children's ideas seriously. Find out what words children use to express ideas children already have about a phenomenon or situation.
2. Challenge children to find evidence for their own ideas.
3. Organize whole-class discussions so that different ideas about the same things can be brought together.
4. Offer them a scientific view as one worth trying as well as others.

5. Provide challenges for them to use new or modified ideas in trying to solve other problems or to make sense of new experience. (p. 86-87)

The guidelines give a general idea of what teachers should do to help students change their ideas. They do not suggest that teachers attempt to follow all five guidelines in every lesson, but rather, they help teachers recognize ways to bring about change in children's ideas. The classrooms in this study were assessed to see whether they offered a climate for conceptual change.

Classroom One

Classroom One appeared to meet the recommendations for contributing to change in children's ideas. Teacher One did not meet each guideline, but she used an additional step that was not included in the original set of guidelines.

Children's language. Teacher One endeavored to find out what her students knew about a topic prior to instruction. She used the initial Idea Invitation Question to uncover student ideas. At this point she encouraged students to share their ideas in response to her question. She also used Probing Questions to help her own understanding of her students' ideas. She showed interest in knowing what students think is happening and in helping them reconcile child and adult usages of language. She used terms the students used, such as "peopled," to communicate with them.

Teacher One used student ideas to inform her teaching within the limits of whole-class instruction. Some ideas were not addressed, but she did use ideas in choosing strategies to present information, such as the Developing Lesson, Literature Connection, or Explanation Strategies. She gave students opportunities to try out their ideas by allowing them to manipulate objects that represent objects in space to practice their thinking about ideas such as orbits, revolutions, and the causes of day and night.

Challenge children to use evidence. Teacher One orchestrated many discussions during her science periods. These discussions took place during large and small group settings. During these discussions Teacher One often confronted students with their own ideas. For instance, in a large group setting, one student believed gravity did not work in water. She asked the student to think about what would happen to the water if no gravity was present there.

Bring together different ideas. Again, Teacher One held daily discussions in whole and small group settings. During the discussions all students were encouraged to share their ideas. Many ideas were elicited in both settings. Teacher One raised questions to help students think about ideas that made the most sense in explaining the idea. Students in Classroom One were thus exposed to many other students' ideas during the course of the astronomy unit. Teacher One recorded their ideas on the white board in the classroom and left them displayed during the course of the unit. It is not certain whether the students adopted other children's ideas, but they were aware that other children expressed ideas that may have been different from theirs, and those ideas were also acknowledged, sanctioned, and questioned by the teacher. Teacher One was careful to state that all students did not have to agree about a certain idea.

Suggest a scientific view. Teacher One used a variety of strategies to offer students scientific views, such as Literature Connections, Explanations, Demonstrations, and Specially Designed Lessons that confronted their ideas. Teacher One did not focus students to note a "right" answer, but rather guided them toward a more scientific viewpoint. An example is when she read students a book to help them obtain a more scientific viewpoint of what makes stars look like they twinkle. Students were not required to know an accurate scientific idea, but were required to improve their early ideas that stars flashed on and off to make them twinkle.

Provide challenges for applying new ideas. Teacher One did not provide new challenges or arenas for students to apply new ideas. There were no examples in which students were asked to apply their knowledge to new situations. However, an area which seemed important in Teacher One's teaching that seemed to contribute to change in ideas that is not on the Guidelines (Osborne, 1985) list, is the revisiting of ideas in a variety of settings. Teacher One revisited certain ideas, such as gravity, and the cause of day and night, in small and large group settings, and several times over the course of the unit. This "revisiting" of ideas allowed students to reinforce and confront their thinking about the concepts several times during the course of the unit. During the revisiting of ideas, she questioned students for their ideas, presented science content using an Explanation, Demonstration, or Literature Connection Strategy, and questioned them for their ideas again. Student ideas about those concepts improved as evidenced by their responses on the pre- and post-instruction interviews.

While Teacher One did not ask students to apply their ideas in new settings, she did use instructional approaches that met the guidelines in the other suggested areas. She additionally used a strategy not in the guidelines that seemed to influence change in ideas, specifically, Revisiting Ideas over and again during large and small group settings. Emphasizing and Revisiting certain concepts in the classroom helped students develop more accurate conceptions of the ideas.

Classroom Two

Most areas of the Guidelines (Osborne, 1985) were also met in Classroom Two. However, there were often opposing methods of teaching by Teacher Two and the Intern Teacher and it seemed the guidelines were not met as well in this classroom. Because Teacher Two and the Intern Teacher both had significant roles in teaching astronomy to students in Classroom Two, the teaching of both were evaluated against the criteria.

Children's language. Both Teacher Two and the Intern Teacher elicited student ideas. Teacher Two endeavored to know student ideas in their own language, by asking them to describe their own ideas in response to her Idea Invitation questions. She probed the students for further information by using Probing Questions. The Intern Teacher also used Idea Invitation questions but was often surprised by student responses, and either rephrased her questions in hopes of getting the kinds of responses she expected, or led the students to her expected responses.

Challenge children to use evidence. Teacher Two encouraged students to think about what they were saying about an idea to see whether it made sense. She also raised other questions related to their ideas to allow students to see whether their ideas could explain other situations. Students were encouraged to consider different explanations in both large and small group discussions. Teacher Two challenged students in discussions using Probing Questions to confront evidence for their ideas. She generally raised points that required students to use their ideas and find out the ideas were not sufficient in explaining the phenomenon. Teacher Two did not lead any activities where the students investigated objects for themselves.

The Intern Teacher took students' ideas seriously in the sense that she was surprised they would respond in unexpected ways. She did not address student ideas but rather tried to focus students on appropriate responses they "should be" giving. While she engaged students in hands-on activities, she did not use those activities as ways to encourage students to confront ideas. The Intern Teacher did not challenge students to find evidence for their ideas. She did hold initial discussions about the event but did not ask students to confront their ideas. She generally asked students following an activity to explain why they thought she had them do the activity but did not actually attempt to see how their ideas may have changed. She was more focused on having students follow the appropriate procedures for conducting the procedures and in staying on-task.

Bring together different ideas. Teacher Two and the Intern Teacher both used the Idea Invitation questions to encourage students to share their ideas about a concept. All students were encouraged to share ideas, though Teacher Two was more adept at encouraging more students to share. Teacher Two also held whole-class discussions following activities that allowed different ideas that had occurred in activities to be shared, and then for students to come to a similar understanding of an explanation that seemed to work for the phenomenon. During whole group discussions students became exposed to other students' ideas. It is not clear whether the students tried out other students' viewpoints, but they were able to hear and share different ideas. During small group settings Teacher Two sometimes asked students to share their ideas with others at their table and asked students to help each other interpret information gathered from books.

Suggest a scientific view. Teacher Two offered scientific explanations in the fashion of Literature Connection, or Explanation Strategies. She recognized that students would not come to full scientific understanding and did not hold them to that specific perception. She, however, did have difficulty with her own content knowledge, which limited the effectiveness of her discussions with students.

The Intern Teacher, however, was frustrated when students could not present the accurate information she had taught. She believed that students with good memories would recall the factual information and that she would know what they understood. Her questioning strategies were used to lead them to stating a "right" answer, whether or not they understood the concept.

Provide challenges for applying new ideas. Neither teacher in Classroom Two challenged students to apply their new ideas in different settings. Students were, however, asked to repeatedly revisit certain ideas. One such idea was the concept of the apparent changes in the moon. Again, students were asked to observe the moon over the course of the unit and discussed the changes they had seen. Students participated in a demonstration activity where they could see a simulation of why the moon apparently changes. This revisiting of ideas did not occur in the same fashion as in Classroom One's revisiting of ideas in small and large group settings. In Classroom Two the revisiting of ideas occurred only in large group settings, but it seemed that Revisiting Ideas made an impact on changing student ideas.

Thus, instruction in both classrooms provided elements of teaching to encourage change in ideas, and offered an additional element of Revisiting Ideas that seemed to also contribute to change in ideas. Teacher One was able to meet the criteria more readily than Teacher Two because in Classroom Two the Intern Teacher often taught in ways that opposed changing children's ideas. The following section describes how children's ideas influence teaching.

The Role of Children's Ideas in Science in Teaching the Primary (K-3) Grades

The main reason for conducting the current study was to define how children's ideas did, or did not, influence instruction in primary science teaching. It was found that indeed, children's ideas are recognized and interpreted similarly to how they are defined in the research literature by these experienced teachers. It seemed that experienced teachers were aware of, and expected, students to respond to queries with their own ideas. Because student ideas were anticipated, experienced teachers developed ways of eliciting and addressing those ideas to help change them toward more accurate ideas. These more accurate ideas were not held to scientific precision, but instead required students to develop better understandings than what they held prior to instruction. The experienced teacher with the highest level of content knowledge was most able to address student ideas in instruction.

The inexperienced Intern Teacher in the study was also influenced by student ideas in that she found ways to respond to the unexpected expressions students made.

These responses by the Intern Teacher were not conducive to encouraging students to express their ideas, but actually hindered student expression of ideas. The Intern's strategies for addressing ideas were focused on helping her ability to deliver content as she believed was necessary without be interrupted by student ideas. These strategies limited the amount of time that students in Classroom Two received instruction that helped them change their ideas.

Further discussion of the role of children's ideas is made in Chapter Five. Comparisons are made of results from the current study with those from previous studies. Chapter Five draws conclusions from the results and makes recommendations for teacher education and future research regarding children's ideas.

Chapter V

Discussions and Implications

Introduction

This study investigated whether and how primary teachers recognized and elicited student ideas, whether and how they addressed those ideas, and the effects of teacher practice on student learning. The purpose was to gain insight into the role of children's ideas in science in teaching the primary grades. The primary teachers in this study taught science as a separate subject, but the results must be understood differently than if the study were conducted in a middle or high school classroom. The teachers' goals for teaching science were often mediated by the language arts program. These goals are significantly different from a high or middle school science curriculum. Consequently there is some discussion that provides a context for sharing results. The first section discusses science in the primary classroom. The second section concerns factors that determine whether and how teachers address student ideas. The third section relates teachers' conceptions of student ideas to their teaching practice. The fourth section describes the effects of practice on student learning. The fifth section discusses the role of children's ideas in science in teaching the primary (K-3) grades. The sixth section describes implications and recommendations for elementary science teacher education. A section discussing limitations of the study concludes the chapter.

Science in the Primary Classroom

Chapter I indicated that helping students develop literacy is the major role of primary teachers. Both teachers in this study agreed with this premise. Given that both experienced teachers had reading and literacy teaching specialties it is not surprising they would use these strengths as a springboard to teach other subjects such as science. Neither teacher had a specialization, nor particular interest in science, yet both recognized science as an important topic to include in a primary classroom. Including science in the primary curriculum was important but not solely for the purpose of providing students with scientific knowledge. Teacher One believed students enjoyed knowing about the world and wanted to read non-fiction books. Teacher Two believed science concepts were interesting to students which would motivate them to learn more about reading and writing. The Intern Teacher believed science should be integrated with language arts to help students learn science. All teachers expressed a belief that a major goal in their science instruction was to help students develop a positive attitude toward science and to maintain their interest and wonder at learning about the world. These goals mesh well with Harlen's (1985, 1996) recommendation for elementary teachers to help students develop positive attitudes toward science.

Science in these primary classrooms provided students with a purpose for reading and writing. It provided the class with interesting topics for discussion that enabled the teachers to help students develop oral language skills. Science also provided a setting for students to communicate their ideas formally in an oral and written fashion through presentations of their work. Science was a way to help children learn to talk about the world, how to ask questions, negotiate and share meanings, and organize thoughts about what was being learned into a communicable form. Thus, the teachers' explicit goals for science were related to attitude, while the implicit goals were related to developing literacy.

While science played a key role in providing a purpose for reading and writing, language arts played a role in helping students learn science. The entire science program in each classroom was infused around the language arts program. There was much writing and organizing of ideas with individual reports, much discussion and negotiation of ideas in each class. Considerable classroom writing time was devoted to astronomy, either fiction or non-fiction stories, in addition to students writing their own research reports. The reading time was solely devoted to children reading astronomy books from which they were to take notes about their topics. Student independent reading helped develop scientific knowledge by having students learn to select reading materials to find information about their topics. Additionally, when the teachers read books to the class, the books were often astronomy related and generally non-fiction rather than fiction. This type of integration of science with language arts is not atypical for an elementary classroom, particularly given the charge of elementary teachers to produce literate readers and writers.

Students learned organizational skills to help them present their work in a communicable form for written and oral presentation. Students developed oral and written language skills by expressing their ideas gained from readings and experiences. These skills are consistent with the *National Science Education Standards* (1996) recommendations for students to construct reasonable scientific explanations based on their experiences, and to communicate their explanations in written and oral forms. Students developed skills of searching through non-fiction sources to draw together information regarding topics of their choice. Science in these two classrooms was a way to help children learn to use language as a means of organizing, expressing, and communicating ideas. Pre- and post-instruction content interviews indicated that these language arts experiences aided students in both classrooms in making notable gains in their knowledge of astronomy as compared to both teacher and *Benchmarks* goals. Through a comparison of pre- and post-instruction student interview responses, it was found that in these two classrooms use of discussion, writing, reading, developing categories of information, and hands-on exploration, was used to build greater knowledge of astronomy.

Science in these primary classrooms was also a way to help maintain student interest in learning about their world. While the teachers wanted students to learn science content, their stated goal was to help students become better aware of ideas related to astronomy and to help students maintain their interest in learning about their world. They did not hold students accountable for knowing a precise amount of knowledge but instead encouraged students to raise their own questions, discuss their thinking, and strive to find ways to answer their own questions. This emphasis allowed students to focus their study in a direction that interested them, and for the study of astronomy to remain personal. The teachers recognized that students were interested in science, and particularly astronomy. Some may question whether it is age-appropriate to even teach an abstract content area such as astronomy in the second grade, and whether the teachers' objectives were appropriate to second grade. The teachers themselves questioned the wisdom of teaching astronomy, yet knew students would have been exposed to ideas of "outer space" by the time they were in second grade. The teachers reported that a high-interest topic such as astronomy would motivate children to learn more about the content. The teachers were aware of age-appropriateness of various concepts within astronomy and recognized that some concepts, such as wormholes, were best left untouched. However, they did not discourage students from studying concepts others may think were beyond second graders' capabilities. For instance, the individual research project resulted in a student in Classroom Two to select "black holes" as a topic. Teacher Two voluntarily expressed that it was questionable whether this student could develop a conceptual understanding of black holes, but she allowed the student to continue studying black holes because it motivated her to continue with her research. Teacher Two also wanted the student to recognize the difficulties associated with understanding complex concepts and presenting them to someone else. It is questionable whether a second grader could know the difficulties of knowing and presenting complex concepts to others. Both teachers expressed the desire to encourage students to learn to their the best of their abilities and not to discourage students from science by telling them they could not study a certain idea. Thus the teachers focused on key concepts defined in part by the limits of their own knowledge.

Teachers used science concepts for three purposes: (1) to serve as a key to teach reading and other literacy skills, (2) to maintain student interest in their learning, and (3) to help students learn meaningful content that would give them a foundation on which to build deeper knowledge. These primary science goals are different from secondary science goals where students focus on a specific body of content knowledge. *Benchmarks* (1993) recommends primary students to learn that (See Appendix B): (1) There are more stars in the sky than anyone can easily count, and they are scattered unevenly and are different in brightness and color, (2) The sun can only be seen in the daytime, but the moon can sometimes be seen at night and during the day. The sun, moon, and stars all appear to move slowly across the sky, and (3) The moon looks a little different every day, but looks the same again in about four weeks. For secondary students the *Benchmarks* (1993) recommends more specific content related to (1) elements stars are made of, differences in stars in temperature and age, (2) scientific evidence that points to the universe being over ten billion years old, and the theory of the universe's development, including fusion and exploding stars, (3) increasingly sophisticated technology is used to learn about the universe, and for the students to know those technologies, and (4) mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe. The *Benchmarks* (1993) recommend more general knowledge for primary children and more factual knowledge for older students.

Eliciting and Addressing Student Ideas

Previous research on children's ideas has generally not included classroom observations (i.e. Bar, 1989; Hashweh, 1988; Nussbaum & Novak, 1976). Researchers studying changing children's ideas did not determine whether teachers shared the same conception of student ideas as the science education literature. Researchers studying children's ideas did not determine whether teachers recognized student ideas, or the importance they played in learning. The current study addressed these concerns by including observations of all classroom activities, and by interviewing teachers for their conceptions of the importance of student ideas. These interviews were triangulated with observations, and it was found that the teachers did not use the same terms in describing student ideas as were used in the research literature. In spite of these differences, teacher interpretations of student ideas included components of perceptual dominance, structure, persistence and coherence found in the research literature. The teachers were able to help some students change their conceptions of astronomy to more scientific understandings as will be discussed below.

Elicitation of Ideas

A focus of literacy education is to foster student oral language development. Primary teachers are adept at orchestrating discussions to help students develop their oral language. Both Teachers One and Two used Idea Invitation and Probing Questions to orally elicit student ideas. Teacher One also elicited the same ideas repeatedly, in small and large group settings to track changes in conceptions. The experienced teachers elicited ideas in small and large group settings, using Idea Invitation and Probing Questions. The Intern Teacher only elicited ideas in large group settings using an Idea Invitation Question. She did not use Probing Questions and, in fact, used a variety of strategies that discouraged student expression of ideas, such as Ignoring, Leading, and Partial Acknowledgement. Her lack of experience and awareness of student ideas as serious conceptions hindered her ability to encourage students to express ideas.

Teachers did not elicit student ideas specifically to change those ideas toward scientific accuracy though that was one of their goals. In fact, the experienced teachers recognized it was not possible for them to help all students develop scientifically accurate ideas. Teaching students accurate content was secondary to goals for developing literacy. Teachers' reasons for eliciting student ideas ranged from wanting to: (1) know what their students thought about the content prior to instruction to help them know at which point to begin instruction, (2) assess development in understanding of a concept, (3) help students learn to express ideas and interpret what they experience, and (4) gain a sense of the range of thought applied to astronomy concepts. The last three goals parallel language arts goals of purposeful communication through reading, writing, speaking, and listening (IRA/NCTE, 1996). Indeed, language arts methods texts recommend elementary teachers hold class discussions and writing activities regarding a shared experience to help students develop understanding of the content and their own skills of communication (Rubin, 1995; Templeton, 1995; Tompkins & Hoskisson; 1995, Tway, 1991).

There were instances in each classroom where students held ideas that were not elicited. A description of one such instance is in Chapter IV (pp. 218-220). The student whose idea remained hidden received no instruction and did not change her idea. From this case it might seem that it is important to note all ideas so they can be addressed in the classroom enabling all children to develop accurate ideas. Yet, how feasible is this in classroom practice? The girl who categorized stars as “regular, shooting, and wishing” was the only student in either classroom identified by the researcher who held such an idea. It would not have been a good use of classroom time to address an idea held only by one student in a whole-class setting. Certainly others in the class may have held the same idea, but if so this was not expressed either in interview or classroom setting. Instead, what the teacher did made more sense. She talked to the whole class about a more accurate perception of the shape of stars as circular. However, it is known from pre-instruction interviews that many other students shared the idea of the student who believed the moon did not turn. This idea that became public was addressed in instruction. At the post-instruction interview students had more accurate perceptions of how the Earth, moon, and sun moved in space. It was a better use of classroom time to address the idea that was shared by many students than one that was shared by only one.

However, the reason Teacher Two and the Intern Teacher addressed the student's idea was not because most students shared it. They did not attempt to make a determination of how many students shared the idea that the moon did not spin but addressed the idea because it was expressed. They did not address the other student's idea about star categories because she was not able to express it in class. Thus, it is more likely that ideas are addressed if they are expressed and are known by the teacher.

Responding to Student Ideas

The teachers made a concerted effort to guide student ideas toward convergence on one idea that could be shared by the class. They guided students using a variety of strategies. Teacher One had a wider repertoire of strategies to use, such as Lesson Development, Explanation, Demonstration, Literature Connection, and Scaffolding. True to her claim, she planned activities to address specific student conceptions. Teacher Two used fewer strategies (Explanation, Literature Connection, and Activity Debrief) to address student ideas, and had fewer opportunities to do so given the fact that the Intern Teacher was required to also teach. The Activity Debrief Strategy was used at the end of hands-on activities that were presented by the Intern Teacher to help students draw sensible conclusions from the activities. Though teachers were aware students would not come to completely scientific understandings of concepts in astronomy, they believed students could come to an agreement about the meaning of concepts.

The choice of responses to student ideas was dependent on different factors such as whether teachers found (1) ideas were too abstract, (2) ideas were shared by many students, and (3) there was sufficient time to address the idea. If teachers found the idea was too abstract, they would either wait until it was thought the students could handle the idea, or did not address it. Their decisions for whether the idea was too abstract depended on the kind of response they received from students. If students responded in such a way as to show no knowledge at all of the idea, it was deemed as too abstract. If student responses indicated they had heard the term, or had some formal idea, the idea was pursued. If the idea were shared by a sufficient number of students, the teacher responded to the idea. Generally, teachers assumed the idea was shared by a sufficient number of students if several students could carry on a discussion about it. For example, in Teacher One's classroom several students discussed their idea that gravity did not work in water, and that was why objects would not always sink to the bottom. Teacher One chose to address this idea in a whole class setting through questioning students about the validity of their idea that helped them reconsider factors they may not have previously considered.

Both teachers chose to address most ideas that were not too abstract. The teachers chose from their own repertoires. Teachers selected a strategy based on the knowledge they believed students held and how much input was needed to help them develop that knowledge, in addition to how many students they believed held the idea. When many students responded to a question with a common, unconventional idea, Teachers One and Two often used a Literature Connection Strategy and shared with them a non-fiction tradebook to try to explain the concept to many at once. For example, when asked whether stars really twinkle, most students agreed they did. Teacher One read a non-fiction tradebook that described the cause of "twinkling" as the light from the star's interaction with the layer of the atmosphere. Of course, this concept could be thought of as too abstract itself. How much understanding can second graders have of the atmosphere? But after hearing the non-fiction book students were able to state that stars did not actually twinkle but only looked like they twinkled because of "how the light went through the air." Thus, though they did not have totally accurate conceptions of "twinkling," their ideas became more in line with the scientific explanation after hearing the story.

While Teacher One and Teacher Two shared similar views of the importance of children's ideas, experience, pedagogy, the learner, and curriculum, Teacher One had greater content knowledge in astronomy, enabling her to more readily adapt her lessons to fit situations that arose during instruction. Experience and subject matter knowledge were important in allowing Teacher One the flexibility to address ideas more freely in her classroom. She had more strategies available in her repertoire, such as Lesson Development, Demonstrations, Explanations, Literature Connection, and Scaffolding. When there was sufficient time to address an idea, Teacher One used Demonstrations with manipulatives and even developed specific lessons to address an idea. For instance, when Teacher One realized students believed that when it was stated that Neptune and Pluto "switched places" in their orbits the planets were actually physically switching orbits, she used a Lesson Development Strategy and planned a specific activity for the next day. The activity used models and role-playing by the students and allowed students to see how an elliptical orbit that overlapped a more circular one could enable a planet to be nearer the sun at some points and further away at others. Thus, specific lessons were designed to address ideas expressed in the classroom given sufficient time to do so.

When student responses indicated they had background knowledge, Teacher One generally found an idea they understood and used that as a point to Scaffold understanding of a different idea. Palinscar (1986) defines scaffolding as a process that enables a child or novice to solve a problem, carry out a task or achieve a goal that would be beyond his unassisted attempts. Teacher One used a Scaffolding Strategy by identifying what students already knew about a concept, and determined to find a similar, related idea to help them explain a new idea. An example of this scaffolding was (Chapter IV, p. 170) when Teacher One used a child's understanding of pierced ears to help the child understand what was meant by "cloud-piercing." She used the child's understanding of the word "piercing" in one context to help her develop an understanding of its use in a new context.

Teacher Two did respond to Student Ideas in two ways that differed from Teacher One. First, when students were thought to hold a fairly accurate perception of a concept and were simply not expressing it clearly, Teacher Two used a rephrasing of students' statements to reflect a correct understanding of the concept. For example, Teacher Two rephrased a students' statement of "the astronauts wear thick clothes so they don't freeze," to "astronauts wear special insulated suits to protect them from lots of dangers in space." She knew the student recognized the protective nature of the clothing, and used a rephrasing of that knowledge to reflect a more accurate and descriptive use of the language. Teacher Two's rephrasing of the expressions of nearly accurate ideas is not unlike second language teachers' rephrasing of sentences second language learners are making to help them become more accurate in English (Allen, 1991; Finocchiaro, 1974; Finocchiaro & Bonomo, 1973; Ovando & Collier, 1985).

Second, she used an Activity Debrief Strategy to help students draw conclusions from the Intern Teacher's presentations of hands-on activities. Her Activity Debrief

Strategy shared components of her strategies for elicitation of ideas in that she asked questions of students to determine what they learned and Probing Questions to determine the depth of that knowledge. She raised questions to help students confront their ideas regarding the content. She used other strategies that were similar to Teacher One, such as Explanation and Literature Connection. She did not use Lesson Development or Demonstration Strategies. Occasionally during her discussions with students she allowed topics to drop because she did not have the knowledge she needed to proceed.

The experienced teachers in this study were more able to quickly respond to students' expressions of their ideas than was the Intern Teacher. They were less concerned with student expression of ideas than what the intern believed were odd and off the track. The experienced teachers realized students would have ideas that were not scientifically accurate and expected to hear such ideas. They were less likely to respond in ways that signified surprise or in belief that they were not asking questions appropriately. The experienced teachers were more likely to respond in ways that encouraged students to confront their ideas. According to Shulman (1987), effective teaching begins with teachers' understanding of content, knowledge of how to represent ideas in a comprehensible fashion to students, knowledge of the learner, and knowledge of the tools that can help student understanding. The experienced teachers in this study were adept at recognizing student ideas, understood the content fairly well, particularly Teacher One, and held adequate knowledge of the learner which enabled them to represent ideas to primary students using a variety of instructional methods.

The Intern Teacher addressed ideas quite differently from the experienced teachers. She found student ideas unexpected and disconcerting. She used strategies such as Ignoring, Partial Acknowledgement, and Leading, that helped her obtain responses more to her expectations. Her methods of addressing student ideas discouraged their expression so she would not have to deal with them. She seemed more focused on eliminating student ideas as being in the way of what she intended to teach. Thus, it seemed with experience teachers will begin to expect, elicit, and address ideas. While the Intern Teacher was able to say the right words and to use the right terminology regarding helping students to "develop schema" and making lessons "developmentally appropriate," she was unable to do so in her classroom practice. On the other hand, the experienced teachers did not use jargon words but simply recognized students would have prior knowledge and sought to know their ideas and use them in instruction.

Summary.

From the methods for responding to student ideas by each experienced teacher, apparently there are a variety of ways to address primary students' ideas in science. Teachers needed to be aware of the depth of understanding of concepts. Idea Invitation Questions enabled Teachers to elicit ideas, while Probing Questions helped them see how strongly ideas were held. Teachers were also conscious of students' abilities to understand and build on concepts. Teachers endeavored to check whether ideas were too abstract for students to grasp. If determined the ideas were not too abstract, teachers used a variety of strategies, each from their own repertoires, such as Literature Connection, Lesson Development, Scaffolding, and Rephrasing, to address student ideas at the primary level. The experienced teachers in this study were aware of the developmental levels and capabilities of their students, and were able to use that knowledge to help them present concepts in ways students could understand. Teachers claimed to address ideas individually but actually addressed ideas depending on the number of students who shared ideas. It makes sense to address ideas that are shared by the most students. With limited time, teachers must make decisions to whether and to what extent to meet the needs of students. It is a more efficient use of limited classroom time to address ideas shared by the most students rather than spend time focusing on just a few. The teachers most often used their experience to teach broad ideas across the classroom, not to address individual ideas. This finding, that teachers present material that addresses most students' needs, is consistent with previous research regarding expert teachers (i.e. Berliner, 1987; Bromme, 1987). While teachers were not aware of each student's ideas, student ideas were similar enough in most instances for the teachers to be able to elicit ideas from some students and address those and have most student ideas addressed. Students in these two classrooms substantially improved their knowledge of astronomy to different degrees as evidenced by responses to pre- and post-instruction interviews.

Teachers' Conceptions of the Importance of Children's Ideas and Teaching Practice

Teacher One was the most effective at, and had the most variety of strategies for, addressing student ideas. She was also the teacher with the most experience and with the highest level of content knowledge, and the most opportunity to address ideas. Teacher One did not express concerns with her own knowledge of astronomy. She seemed to have the knowledge that allowed her to switch the focus of her lesson to address new and unconventional ideas. She was able to hold conversations with the second graders about abstract concepts and they were able to comprehend and discuss the concepts at a fairly high level. She held relatively few hands-on activities, none of which were pre-planned. All hands-on activities were planned to address specific ideas.

Teacher One expressed a belief that listening to student ideas would be a key to understanding what they know and she could adjust her instruction accordingly. Teacher One did, indeed, listen to her students and encouraged them to express their thoughts. She often stated to the researcher that she enjoyed listening to the students and was impressed with their reasoning through difficult concepts. True to her expressed belief, she elicited ideas by using an initial Idea Invitation Questioning strategy consisting of asking a question to the large group, or to an individual, depending on the situation. She continued eliciting ideas through Probing Questions where she continued her line of questioning in a cyclical fashion, checking to see if ideas had changed, and to see how many students shared the same ideas. When she had evidence that many students shared an idea, and that they were capable of developing an idea that was more scientific, she used it to help inform her teaching. She stated she used student ideas to adjust her instruction, and in fact, often did so. She addressed student ideas through strategies of Explanations, Literature Connection, Demonstration, and Scaffolding based on concepts students were already familiar with, or Lesson Development. Student ideas did influence Teacher One's teaching practice.

In Classroom Two the picture was a bit different. Teacher Two had 10 years of experience teaching first and second grades and the same number of years' experience teaching second grade astronomy as Teacher One. The Intern Teacher was, of course, new to teaching and quite inexperienced. Teacher confidence was not a focus of this study, but Teacher Two and the Intern Teacher repeatedly expressed self-doubts about whether they knew enough about astronomy. Previous studies have shown that teachers with weak content knowledge lacked confidence (Borko, 1993; Enochs & Riggs, 1990;

Smith & Neale, 1989), even though they may be enthusiastic (Abell & Roth, 1993). Dobey and Schafer (1984) found that elementary teachers with high or moderate levels of content knowledge had greater confidence in teaching science using inquiry than teachers with lesser content knowledge. Teacher Two's knowledge was indeed weaker than Teacher One's. Teacher Two was also very adept at eliciting student ideas through Idea Invitation and Probing Questions but was not as malleable with her teaching to address those elicited ideas. She did not cycle ideas through the class in large and small groups, but addressed them only once and in the setting they were raised. In addition some of her lines of questioning were dropped before a concept was addressed because Teacher Two did not have the level of knowledge to present it to students. She also was constrained by having the Intern Teacher in the room who presented all the hands-on activities. She did try to help students draw conclusions to those activities through an Activity Debrief Strategy. Teacher Two did use Explanations and Literature Connections Strategies and persisted with helping them think through ideas by her Probing Questions. She was adept at finding out what students did know. Dobey and Schafer (1984) found that teachers with high or moderate content knowledge were more willing and able to adapt their teaching. This finding was confirmed in the current study. Teacher Two and the Intern Teacher had lower levels of content knowledge and were less adept at adapting their teaching to student ideas.

Though the experienced teachers' definitions of student ideas could be argued to be similar to the definitions found in research literature, the Intern Teacher defined children's ideas differently from the experienced teachers. The Intern did not believe the students would develop ideas on their own about the world through experiences but through exposure to media such as television, particularly cartoons. She thought of children's ideas as areas in which students had studied and had become experts. She claimed to use her students as "experts" when teaching new content. Though she elicited student ideas through an initial Idea Invitation Question Strategy in whole group setting, she did not allow those ideas to influence her instruction. She was often frustrated by student responses and stated she thought if she could ask the questions in the right way, she would get the responses she expected, which were more in line with accurate conceptions. With whatever responses she received, she delivered instruction as planned, either as given by the mentor (Teacher Two) or her own plan. Within her planned activities, she used strategies such as Leading, Ignoring, and Partial Acknowledgement, that discouraged further expression of ideas and enabled her to continue with her lesson delivery. The Intern Teacher had the most detailed lesson plans to guide her instruction. Teachers One and Two did not use complex lesson plans, but merely jotted notes to themselves in a plan book. The notes were brief and sometimes included only one word, such as "research." Primary teachers with more experience need to spend less time writing plans and are still able to deliver lessons that allow students to learn and change conceptions. This conclusion is similar to Carlsen (1991) in that novice's lesson plans differ greatly from experienced teachers' planning, particularly because novices generally have different subject matter knowledge structures. In addition, experienced teachers are more likely to be willing to deviate from their plans than novice teachers.

The Intern Teacher did not ask students to explain their reasonings and understandings while they were manipulating materials and conducting investigations. The Intern Teacher sometimes presented inaccurate information to answer a question.

The experienced teachers simply did not teach something they did not understand but would tell students they, as a group, could figure it out, or that the teacher would find out and tell them later. The Intern Teacher was aware of the importance of teaching developmentally appropriate concepts but was not aware of where that line should be drawn in the second grade classroom. Though her mentor cautioned her against some of the activities and terms she used, she continued to use them. She did not have enough experience to know what was "right" for second grade. She also was not aware of student ideas and was surprised when students responded in unexpected ways, and ignored or corrected them while the experienced teachers encouraged sharing of many ideas but focused students on a convergence of ideas. The current study confirmed Shulman's notion (1986, 1987) that experienced teachers are better at representing knowledge in ways comprehensible to children.

Limitations to Responding to Ideas

The teachers' belief that knowing students' thinking is important and that it influenced their teaching were not always confirmed in their instruction. The teachers' abilities to respond to ideas in ways consistent with their beliefs were mitigated by different factors. Clark and Yinger (1987) found that teachers were more likely to teach in a manner consistent with a belief they strongly held. However, previous studies have delineated factors that limit teaching in manners consistent with beliefs (Calderhead, 1987; Huberman, 1985). These competing factors include a concern with classroom management and colleagues/parents. In the current study the concern with classroom management and colleagues and parents was not manifested except in the case of the Intern Teacher. The Intern Teacher was quite concerned with management of the classroom, particularly of small group activities. This finding is consistent with Hollingsworth (1987) that a major concern of all intern teachers is classroom management. Because the Intern Teacher was distracted by management activities, she did not respond to student ideas during settings where they were investigating materials but instead focused students on following appropriate procedures. Her concern could be attributed to inexperience in dealing with inquiry and other activities. The Intern's focus contrasted with Teacher Two's questioning of students as they were experimenting. Teacher Two, with fewer management concerns and more teaching experience, was able to ask questions of students as they manipulated objects that required students to give explanations of what they were doing and seeing. The Intern Teacher emphasized procedures in her lesson plans rather than discussion of ideas or meanings. She did not want to lose control of the class in front of either her supervisor or Teacher Two.

There are other factors that influence teaching in any classroom setting, and indeed, often a cost-benefit decision is made (Calderhead, 1987). In these two classrooms the cost in time was the greatest consideration against the benefit of student change in knowledge. Labbo, Field, and Watkins (1995) also found that a third grade teacher was often constrained by time and based instructional decisions on whether there was sufficient time to allow her to present a lesson. The astronomy unit was taught toward the end of the school year and the teachers began to feel strained by the limited time they had left in the school year. When an idea or concept would take more than the available time to address, the teacher decided not to respond. One such example was the idea of constellation in Classroom One. Teacher One intended to deliver instruction on constellations and relate it to the story she had read at the beginning of the term but was not able to find time prior to the end of school to do so.

Another reason for not addressing an idea was a teacher's incomplete understanding of the concept. When the teacher did not understand the concept it was often heard but not addressed. An example is from Classroom Two where Teacher Two did not follow through in her discussion of the spinning of the Earth because of her own lack of knowledge (Chapter IV, p. 194). However, when teachers had sufficient time to learn about a concept, they often used that idea as an impetus to their own learning. Teachers One and Two both read books and researched information about concepts students had questions about and then brought their research back to their classes. Again, the key was sufficient time to do the research and present it to the class.

Another reason for not addressing an idea was lack of materials. Teacher One wanted to demonstrate the movements of the Earth, moon, and sun using a professional model, but was unable to locate one. Thus, she was unable to use that demonstration. She did use a teacher-made model, but thought she could do a better demonstration with a proper model. Her belief that a specific model would be required to present a concept could indicate lack of understanding various representations of a concept (Shulman, 1986, 1987). MacKay and Marland (1978) found that classroom climates required teachers to make numerous decisions at rapid paces. Thus, teachers choose from limited alternatives when selecting instructional activities. As in Classrooms One and Two, it is sometimes difficult to know on what teachers are basing their decisions because they appeared unstructured and unplanned, particularly when listening to children's thinking (Fennema, Franke, Carpenter, & Carey, 1993).

Teachers' Conceptions: Importance of Children's Ideas and Student Learning Outcomes

Teachers in the current study were aware that students would express ideas that were not conventional and claimed these expressions were important in their teaching. Their openness and encouragement of students to express ideas allowed students' ideas to become public. Students in the current study were accustomed to discussing their ideas publicly with their teachers and peers. Because ideas became public teachers were able to address them in instruction. These students were able to describe their understandings to the researcher during interviews showing an improved understanding of many abstract concepts in astronomy. Because teachers were aware of student ideas, they were able to address them in instruction and encourage conceptual understanding. In other words, teacher awareness of student ideas contributed to student learning outcomes, though both teachers accomplished this differently and to different degrees. The teachers sought to know their own students' ideas with the intention of planning lessons to address those ideas accordingly.

Two distinct approaches to teaching science existed in the two classrooms. In Classroom One nearly all instruction proceeded through a discussion mode. Teacher One used a variety of strategies such as Demonstration, Explanation, Literature Connection, Scaffolding and Lesson Development, to encourage discussion, address ideas, and to deliver content. Few hands-on activities were pre-planned for student engagement, though they were developed in response to student expression of ideas. In Classroom Two students participated in a hands-on activity each day. Student knowledge was greater in Classroom One than in Classroom Two at the conclusion of the units. In fact, students in Classroom Two, where students received a hands-on lesson on gravity, had a less accurate conception of gravity than students in Classroom One where students participated in repeated discussions in large, small group, and teacher/student dyad settings. This study confirms Butts, Hofman, and Anderson (1993) who found hands-on activities alone are not sufficient for conceptual understanding. What is required is a conceptualization of the meanings of the hands-on activities by the student. Discussion of interpretations students make is an important factor. The current study differs from Feldman and Acredolo (1979) who found that active learning is better than passive learning. They found students who were actively involved in learning were better able to find their ways through an unfamiliar hall than students who passively followed an adult. It could be thought that students in Classroom One who received fewer hands-on lessons were passively following the teacher's explanations. However, it is more accurate to state that though they engaged in fewer activities, they were cognitively active in thinking about concepts that were abstract. Perhaps it is the cognitive activity that is more important than the manipulative activity. The cognitive activity via discussion of concepts helped students consider alternative ideas they may not have simply by manipulating objects.

Several significant ideas related to teacher practice changed in each classroom. Prior to the astronomy unit many students in both classrooms thought the sun and the moon were planets. At the conclusion of the unit no students in either classroom held the belief rather all students spoke of the sun as a star and the moon as a satellite. After recognizing that several students considered the moon a planet, Teacher One held a short discussion using a Literature Connection Strategy related to a book she was reading that is described in Chapter IV (p.168). She checked to see what students believed about the moon and then affirmed responses that "what goes around the sun is a planet, and what goes around a planet is a satellite." Thus, Teacher One checked for student understanding and provided an accurate definition. In Classroom Two, the Intern Teacher held a discussion about the moon where she asked the student who was studying satellites to provide a definition for the class. True to her claim of using students as experts, she asked an "expert" on satellites to provide an explanation to the whole group.

In both classes a significant improvement in the conception of why there is day and night existed. Teacher One revisited this idea several times throughout the course of the unit. She used Idea Invitation and Probing Questions, in small and large group settings, to ask students to explain what they thought made day and night. She then either had students demonstrate, or she used a Demonstration strategy to show the way the sun, moon, and Earth move using models. She elicited student understanding of the idea through Idea Invitation Questions and then addressed it through the use of a Demonstration Strategy. A greater number of students in Classroom One had a more accurate understanding of the causes of day and night than did students in Classroom Two. In Classroom Two students were exposed to the idea twice. First, they were asked by the Intern Teacher to act in the roles of the sun, moon, and Earth to see how these bodies moved in space, and also imagine on which side of the Earth it was day or night. This role-play was similar to what has been described as symbolic play (Golomb & Cornelius, 1977; Piaget, 1957) because it asked students to imagine an abstract idea through play. Teacher Two also addressed this idea with her class, by holding a whole class discussion regarding what causes the Earth to spin, which became a discussion on day and night. (See Chapter IV, p. 193) During this discussion Teacher Two first elicited student ideas using Idea Invitation and Probing Questions, and then orchestrated the discussion so students converged on a shared meaning of the concept. Again, student ideas influenced instruction in both classrooms by helping determine the focus of lessons. Lessons were delivered differently by each teacher, but student ideas influenced both.

Classroom Two students had weaker understandings of what was visible in the night sky, though they had similar conceptions as students in Classroom One of the daytime sky. This difference seemed surprising considering students in Classroom Two were required to observe the night sky to look at the moon each night and students in Classroom One were not. Perhaps they were so focused on the moon that they did not pay as much attention to the rest of the sky.

Another idea that was revisited again and again in Classroom One was that of gravity. Teacher One often elicited student ideas about gravity over the course of the unit. Students freely discussed their ideas, and Teacher One asked them to confront their ideas with Probing Questions to help them consider what would happen in different situations if gravity were as they believed. She raised Probing Questions such as: "If there were no gravity where there is water, then why doesn't the water fall off the planet?", and "If gravity were different all over the planet, then would things fall off on different parts?" These Probing Questions encouraged students to think about their beliefs, and to reconcile their understandings with responses to the questions. At post-instruction interviews students in Classroom One had a more accurate conception of gravity, and a conception more in line with Teacher One's idea that gravity is determined by the mass of an object and the distance between two objects.

In Classroom Two gravity was formally addressed only once. A guest speaker presented a hands-on activity about the concept of gravity. It was designed to illustrate that a piece of crumpled paper and rock would hit the ground at the same time when dropped, and a crumpled piece of paper would hit the ground before a flat piece when dropped at the same time. Students were to recognize the role of air resistance. While the activity was successful for one student who was able to draw a connection to gravity and lack of air resistance on the moon, most other students did not have a more accurate conception of gravity at the conclusion of the unit than they did prior to instruction. In addition, the Intern Teacher told the class several times during other that gravity pushed on the Earth from the air and that is why things did not fall off. Neither the Intern Teacher nor Teacher Two had accurate conceptions of gravity. Students in Classroom Two received inaccurate instruction in the concept. At post-instruction interviews one student in Classroom Two did not know that gravity contributed to keeping him on the planet, and four of the ten interviewed believed gravity pushed from the air onto the Earth.

Regarding why the moon does not always look the same, students in Classroom Two held more accurate conceptions. They were required to observe the moon on a nightly basis, and discussed how it looked each morning in class. They participated in a hands-on activity, again similar to symbolic play (Golomb & Cornelius, 1977; Piaget, 1957) that required them to act in various roles. They role-played as the moon's orbit or the Earth, while the sun was stable from afar. From their role as the Earth they could see what part of the moon was in view at different points in its orbit. Students spontaneously told the researcher at post-instruction interviews that this activity was one that really helped them learn about the moon. While students did not publicly express ideas about how the moon phases worked prior to instruction, they held a much more accurate conception at the conclusion of the unit. The continual focus on the moon seemed to be a key in their learning. In Classroom One students were not required to observe the moon nor did they participate in any activities regarding the perceived shape of the moon. No students expressed ideas about the moon, either voluntarily, or by being elicited. While students at the post-instruction interview no longer believed parts of the moon went away and came back, students in Classroom One did not have a conception of why the moon looked different, nor that it changed in a cyclical pattern.

From these examples, it is implied that ideas that were revisited were understood better than those that were addressed only once. It is also the case that, ideas that were not expressed nor elicited, were not addressed, particularly if the teacher did not already have a plan to deliver lessons related to the concept. The mode of instruction did not seem as important as having students revisit their ideas many times, and discuss the interpretations they were making of discussions and activities. Revisiting the ideas and providing accurate knowledge through the variety of strategies in each teacher's repertoire can reinforce importance of knowing certain conceptions and can allow students the opportunity to continually confront an idea in different ways.

Both classrooms included elements of the Guidelines for encouraging change in ideas (Osborne, 1985). Both classrooms included instruction in the first four of the following five points:

1. Take children's ideas seriously. Find out what words children use to express ideas they already have about a phenomenon or situation.
2. Challenge children to find evidence for their own ideas.
3. Organize whole-class discussions so that different ideas about the same things can be brought together.
4. Offer children a scientific view as one worth trying as well as others.
5. Provide challenges for them to use new or modified ideas in trying to solve other problems or to make sense of new experience. (p. 86-87)

In addition, each classroom included elements of a new point not on the list that included revisiting selected ideas. Revisiting these ideas seemed to improve knowledge and understanding of the ideas that were revisited. Thus, Revisiting Ideas could be added to the list of Guidelines (Osborne, 1985) for encouraging change in ideas. In Classroom Two the Intern discouraged change in ideas because she discouraged sharing of ideas.

However, the Intern Teacher taught in ways that opposed these points. Her instruction was at odds with what Teacher Two encouraged in the classroom. The Intern's instruction hindered teaching for change of ideas in Classroom Two. In the Guidelines (Osborne, 1985), it is imperative to know the ideas and for students to know their ideas to change them. Students in Classroom Two were discouraged from sharing their ideas when the Intern was teaching so change in their ideas was inhibited.

<u>The Role of Children's Ideas in Science in Teaching the Primary (K-3) Grades</u>

Though primary teachers in this study used different terminology to describe children's ideas, they seemed to hold the same conception of student ideas as is defined in previous research in terms of coherence, persistence, perceptual dominance, and structure. Thus, it is possible to examine the role children's ideas played in influencing instruction in these two classrooms.

A role of children's ideas in science is to provide an avenue for utilizing teachers' instructional strengths in other curricular areas to help them provide effective science instruction. The elementary teachers in the current study used their expertise in language arts to purposely orchestrate discussions devised to elicit student ideas. Because they were interested in developing student oral language, they sought to help students share and discuss their ideas. Science provided a topic for discussion and for sharing ideas. The teachers used children's ideas in science as a way to help children develop their oral language skills by explaining their ideas rationally, as well as a starting point for instruction in science content.

Another role of children's ideas in science is to highlight the kind of knowledge important to science teaching. First, what kind of knowledge is necessary for an elementary teacher to effectively teach science and address student ideas? Teachers of elementary students need to know enough about the subject matter to be able to recognize and address student ideas, but at what point is their subject matter knowledge sufficient, and what other kinds of knowledge are necessary to provide effective science instruction in an elementary classroom and curriculum? Content knowledge alone does not guarantee elicitation of or responding to ideas. Much more is needed, such as knowledge of learners, knowledge of student ideas, and knowledge of pedagogy that can help student confront ideas. Knowledge of how to use science in helping students develop literacy is quite important for primary teachers. Young children are still developing knowledge and use of language (Vygotsky, 1986). Shulman (1987) states teachers need knowledge of a variety of content areas to effectively teach a single content area. Traditionally elementary teachers have been specialists in language arts which may be the reason they are so aware of the need to help children reconcile the difference between scientific and child language. Teachers should receive instruction in helping students reconcile and understand adult meanings of words with their own interpretations. It cannot be assumed that what an adult says will be understood by a six- or seven-year old as the adult intended. Teachers need to be aware of strategies for helping students understand the language of science, and for helping teachers themselves understand what students mean when they are talking about their understandings.

Second, how much knowledge is necessary for an elementary teacher to effectively teach science and address students' ideas? It is a given that the teacher must have sufficient content knowledge to recognize when a student is expressing an unconventional idea. The teacher must have sufficient knowledge of the learner to recognize what students of young ages mean when they express ideas, and how to help those students develop their ideas toward more accurate conceptions. The teacher must know more content than the students to be able to represent it in ways students can comprehend.

Limitations of the Study

As with all studies, the current study has limitations in conjunction with its design. The study provided in-depth information for two classrooms. The advantage of studying two classrooms in-depth was to provide more information concerning classroom practice. Studying only two classrooms limits generalizability to other classrooms and other grade levels. This study focused on only one unit in one content area at one grade level for a limited time period. Because of the limits discussed, results are restricted to the sample discussed in this study.

Student knowledge of content was checked immediately following unit instruction. It was necessary to check understanding at that particular time because school was ending and students left for the summer. More information regarding retention of understandings of abstract astronomy concepts could have been obtained if the researcher were able to check student content knowledge several weeks or months following the unit. Checking content knowledge after a time separation would have allowed the researcher to note any differences in retention of content related to teaching practice.

The researcher introduced limitations in the study. The researcher was the main instrument of data collection and analysis, and thus focused the study in a direction that was contributed to by her own biases, background, and experiences, which limits the conclusions drawn. Being a former primary teacher affected how the researcher viewed the classrooms, and it is possible that someone without that background would have seen the classrooms and instruction differently. However, being a former primary teacher also affected the researcher's content background, not astronomy, but psychology. Simply being in the classroom likely affected what the teachers typically did in the classroom, though they claimed it did not. Both experienced teachers claimed they were not affected by the researcher's presence in the classroom, though prior to the study they believed they would be. Teacher One said the only effect the researcher had on classroom practice was that science was always scheduled at a particular time because she was aware the researcher would be there, so held the science period constant. The Intern Teacher said the researcher did effect her instruction in the manner of encouraging her to be more prepared and to value science more than she probably would have otherwise.

Implications for Elementary Science Teacher Education

The experienced teachers in this study had language arts and reading backgrounds which are representative of most elementary teachers. They expressed the belief that developing student literacy was the most important focus for their work. Though they were not science specialists, they enjoyed teaching science. Both teachers displayed confidence in their science teaching abilities, though Teacher Two continually expressed a concern that she did not know enough science. The teachers in the current study spent much class time devoted to science instruction—a minimum of 300 minutes per week. This finding is unlike the results found in previous studies indicating primary teachers spend little time on science, (Cawelti & Adkisson, 1985; Fitch & Fisher, 1979). Both teachers claimed they did not increase their instruction simply because someone was watching them.

What is important as a result of this study is to recognize the strengths experienced elementary teachers have and how they use their strengths to help their students develop scientific understandings. The teachers in this study were both successful in helping their students develop better understandings, to different degrees, using strategies beyond memorization of content. The following implications for science teacher education can be made from this study.

First, children's ideas influenced teacher planning. All three teachers planned to elicit student ideas, and the experienced teachers intended to address those ideas. Teacher One was so influenced by student ideas that she even developed lessons to address specific ideas. Student ideas influenced instruction in Classroom One such that their ideas about different astronomy concepts were revisited throughout the unit. Teacher One cycled the ideas several times through her instruction, in both large and small group settings. This revisiting of ideas seemed to help students improve in their knowledge of astronomy. Students in Classroom One had the highest level of knowledge. The continual checking for change in ideas allowed Teacher One to continue addressing the ideas with a variety of strategies.

Related to planning to elicit student ideas, inservice and preservice 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. Strategies that appeared to be useful were initial Idea Invitation and Probing Question strategies that required students to discuss ideas and negotiate meanings and understandings of content and experiences in their classrooms. The strategies used by the teachers were specifically directed to knowing student ideas. A further recommendation about eliciting student ideas from this study is that it is not necessary to elicit all 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 recognize 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).

Secondly, teachers in the current study provided many paths for students to change their ideas toward more accurate conceptions. The experienced teachers in this study used several strategies for helping students change their ideas, such as Lesson Development, Demonstration, Literature Connection, Explanation, and Scaffolding. Both preservice and inservice teachers can be introduced to different methods of addressing student ideas based on the success of these experienced teachers, particularly Teacher One. Teacher One cycled ideas through her classroom, addressing them several times in many different ways (see Figure 3), while Teacher Two and the Intern Teacher's strategies did not include cycling the ideas (see Figures 5 and 7). Teacher One's manner of listening and reacting to ideas in the classroom guided her delivery of content. She depended on creating an atmosphere, in which students would share and discuss ideas, so she could address them in instruction. Her cyclical method of eliciting and addressing student ideas can inform the use of the Learning Cycle (Karplus & Thier, 1967) in the primary grades. An implication from this study is that an additional component of the learning cycle should contain a revisiting of ideas over time. Student ideas can be elicited, addressed, and checked again for more accurate conceptions that develop over time. It is appropriate to educate the teachers to recognize the importance of student ideas as persistent alternative conceptions, and to use them as springboards for developing lessons. Revisiting ideas was an important component as a springboard in the most Teacher One's classroom. Previous research has shown that primary aged students hold surprisingly similar conceptions about a variety of science content. Even students in the current study held ideas that were similar to ideas found in previous studies of children's ideas of astronomy (Mali & Howe, 1979; Nussbaum & Novick, 1976). Teachers must have sufficient knowledge to help students confront their ideas, and that knowledge can take more forms than simple content knowledge. It must be remembered that not all interns can handle the sophistication of responding to children's ideas. There are differences between novices and expert teachers, and responding to student ideas may be a skill that develops with experience. Because of these differences and the process of becoming a teacher is difficult, interns are concerned with many other factors (Hollingsworth, 1989).

Third, teachers in this study used science as a way to help students develop language skills and to maintain interest in learning about the world. Children's ideas in science were used as a basis for dialogue and discussions about the science they were learning. The experienced teachers used children's ideas in science to help students develop oral language skills. They also used children's ideas to focus students on books to read and writing topics. This finding implies that science can be used to help students become literate in language arts, which is a major goal in elementary school. Previous research has found that the ability to read is a major factor in a child's choice to remain in school, and that early oral language development contributes to learning to read (Paris & Cunningham, 1996). Science can provide a purpose for oral language development, and for reading, which contributes to literacy development. It is possible that using science to help develop literacy can also help children stay in school. Helping elementary teachers recognize that science can be a tool to developing student literacy can encourage them to teach science. Elementary teachers are typically specialists in language arts and reading. Language arts and reading are topics they are comfortable and confident in teaching. These strengths in teaching language arts can be tapped to allow elementary teachers to use strategies they have developed and used in other subjects to help them provide science instruction. The teachers in the current study taught science on a daily basis with the knowledge they were helping students not only learn science, but also to develop reading, writing, speaking, and listening skills. Science can connect to the interests students have about the world and help them develop literacy skills. It can provide a purpose for reading, writing, and discussion. In the meantime students can be developing more accurate conceptions of scientific ideas, building a new level of understanding on which new ideas can rest. Teachers in the current study developed language and discussion skills in their own students using science as a key motivator.

Fourth, the current study found that even when teachers believed in the importance of student ideas and their influence on teaching, it was not always the case that this belief was evident in their instruction. While both experienced and intern teachers elicited student ideas, the teacher most malleable in addressing student ideas was the experienced teacher with the highest level of content knowledge. An implication is that though it is important to make elementary teachers aware of the effects student ideas have on their learning of science, for teachers to be able to readily and effectively address those ideas they must have sufficient experience with that age of students and the content knowledge to do so. Without becoming knowledgeable in the content they are to teach, teachers may be unable to recognize expression of ideas and to know when and how to address them. Children's ideas in science influenced teachers in the current study to confront their own thinking about science content by questions that were raised by students. It is important for teacher education to provide elementary teachers with the tools to improve their own content knowledge when they are faced with teaching an area about which they are unfamiliar. Student ideas influenced the teachers' desire to improve their own knowledge. Dobey and Schafer (1984) found that teachers with an intermediate level of content knowledge increased their abilities to teach elementary science using inquiry strategies. These findings were confirmed in the current study in that the teacher with the intermediate level of knowledge was more readily able to address student ideas, which is a component of inquiry instruction. When teachers are confronted with student ideas it can provide a reason for them to improve their own knowledge.

Teacher educators must be aware that elementary teachers are sufficiently intelligent and resourceful to be able to find ways to increase their content knowledge if they are given the tools and shown the importance of doing so. Thus, elementary science methods courses can provide experiences wherein teachers can become confident in their abilities to conduct scientific investigations, confront their own ideas, and increase their own content knowledge. Another way to improve content knowledge may be to have interns practice teaching the content. At the conclusion of the current study the Intern Teacher held more accurate content knowledge of astronomy and planned to teach it again when she had her own classroom. Scholz (1996) found that the act of teaching influences subject matter knowledge. Having teachers practice lessons in content areas could improve their knowledge in those areas. This finding implies that providing time for preservice teachers to practice lessons can improve not only their pedagogical knowledge, but also their subject matter knowledge.

In addition to knowledge of subject matter, knowledge of the learner is also crucial to recognizing and addressing student ideas. The Intern Teacher in this study did not recognize student responses as being serious ideas. The experienced teachers in this study were aware of the developmental levels and capabilities of their students, and were able to use that knowledge to help them present concepts in ways students could understand. Teacher preparation programs should take the information provided from experienced teachers and have a focus in the program of understanding the learner. Coursework in educational psychology does exist in teacher preparation programs, but primary students are different from intermediate, middle, and high school students. Without explicit instruction in those differences and the capabilities of students in primary grades, teachers will need to learn the same knowledge through experience. Primary children are capable of understanding many ideas and can engage in different activities. The role of early childhood education is to use the children's capabilities of learning from experience to improve their comprehension by creating opportunities for meaningful and challenging experiences (Paris & Cunningham, 1996). These experiences need to be concrete in that they must be something children can at least imagine while they are discussing the idea. One solution to the problem of noticing the differences of capabilities between students of different grade levels is to have preservice elementary teachers participate in internship experiences in both primary and intermediate grades. Providing preservice elementary teachers experiences in multiple grade levels will give them opportunities to note how children differ in their abilities with maturity.

Recommendations for Future Research

Future studies should explore how the strengths of elementary teachers in the language arts skills of reading, writing, and oral language development can be used to improve teaching of science (Flick, 1995). Previous studies have noted similarities between science and language arts processes (Baker & Saul; 1994; Casteel & Isom, 1994; Gaskins & Guthrie, 1994; Glynn & Muth, 1994). A future study that describes how elementary teachers given background in the similarities between science and language arts processes approach science should be conducted. Which language arts skills complement learning in science?

Increased confidence has been linked to increased content knowledge (Abell & Roth, 1992; Fitch & Fisher, 1979). Indeed, a minimum of an intermediate level of knowledge has been shown to improve inquiry teaching (Dobey & Schafer, 1984), and an important component of inquiry teaching is taking into account student thinking. Perhaps increased content knowledge that can increase confidence will influence whether and how teachers address and approach student ideas. Thus, future studies should explore how teachers can improve in their abilities to address student ideas if they are provided instruction in content that raises their confidence in teaching science.

Future studies should explore how providing preservice and novice teachers with instruction in student ideas may influence their abilities to elicit and address those ideas. Preservice and novice teachers would receive background knowledge of student ideas and learn to expect student responses to statements to be unconventional. They would be taught strategies for eliciting and addressing student ideas. Their teaching should be observed and described to see whether they use those strategies in addressing student ideas in their instruction.

Future studies should also focus on differences found between student expression of ideas and teacher knowledge of student ideas. The Intern in the current study was influenced by student ideas but did not have the knowledge for dealing with them. A future study can explore how knowledge of student ideas translates into effective methods for addressing ideas in teaching practice. Specifically, which instructional strategies foster preservice teacher skills in using children's ideas to plan and deliver instruction?

One role of the science teacher educator is to help preservice and novice teachers become experienced and expert in helping their students to learn more accurate ideas of science. A future study can explore how teacher educators can translate the pedagogical knowledge of experienced and expert teachers into forms that can be understood and used by preservice and novice teachers. Specifically, how can science knowledge be structured and presented to teachers to promote a sophisticated understanding of children's ideas?

Another study could focus on, not only how teachers get students to discuss and talk about their ideas, but how to help teachers listen and respond to student ideas. The goal here is to help teachers become more focused on student learning and ideas rather than procedural knowledge. Specifically, what strategies can be used to prepare preservice and novice teachers to listen and respond to student ideas?

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APPENDICES

Appendix A

Informed Consent Forms
(Teacher Form)

Dear _______________,

My name is Valarie Dickinson, and I am a doctoral student in science education. I am beginning dissertation research and would like to request your help in my investigation of primary children's ideas in science and their influences on teaching.

Participation will be in the Winter and Spring quarters, with a conclusion of my involvement in the classroom in June. During the winter and spring terms an interview of you concerning your teaching of science and your plans for science teaching year will be conducted. With your help, some of your class will be selected for individual interviews of their ideas about science. You will assist me in defining a segment of science instruction that I can observe and videotape. Following my review of some classroom videos, I will request you and I view a videotape together, and an interview will take place regarding your views of what is taking place in the classroom. Toward the conclusion of the observed science instructional period I will request a culminating interview with you, and an interview with selected students from your class.

The researcher and major professor will be the only persons with access to all data collected (interviews, observations, notes). Confidentiality will be maintained through use of coding. Pseudonyms will be used for the university and all participants when reporting the results of research. Video and audiotapes will be kept in a locked location until analysis is completed, at which time they will be erased.

Participation is voluntary. You, or any of your students, may discontinue participation at any time.

Questions about the research, personal rights, or research-related injuries should be directed to: Dr. Norm Lederman, 737-1819 or Dr. Larry Flick, 737-3664.

Thank-you for your time and participation in this research project.

Valarie Dickinson, 713-6381

I agree to participate in this research project and understand the general intent of the study, the types of data to be collected, and the time commitments involved in the study.

______________________________ ______________

Signature Date

Informed Consent Form
(Parent/Guardian and Students)

Dear ____________________,

My name is Valarie Dickinson, and I am a doctoral student in Science and Mathematics Education at Oregon State University. I am beginning dissertation research and would like to request your help in my investigation of primary children's ideas in science and their influences on teaching.

Participation will be in the Winter and Spring quarters, with a conclusion of my involvement in the classroom in June. During the winter and spring terms an interview of a selection of children for their thoughts and ideas about science will be conducted, one of whom might be yours. In addition, many hours of classroom observations during science, and other instructional segments of the day, will be videotaped. I will be focusing on teacher-child and child-child interactions and activities during science at the observations. Toward the conclusion of the observed science instructional period, I will request an interview with selected students in the class, again focusing on children's ideas about science content and perceptions of teaching. Each interview of students will be conducted in the school and last about 20 minutes in a manner that will not interfere with normal classroom instruction. The content of the interview itself should be intrinsically motivating and interesting to your child.

The researcher and major professor (director of the research) will be the only persons with access to all data collected (interviews, observations, notes). Confidentiality will be maintained through use of coding. Pseudonyms will be used for the university and all participants when reporting the results of research. Coding and use of pseudonyms will maintain confidentiality of all data provided by children. Participants will not be identified or identifiable in any publications or other means for disseminating results of the study. Video and audiotapes will be kept in a locked location until analysis is completed, at which time they will be erased.

Participation is voluntary. Your child may discontinue participation at any time. Your child will benefit from the interview process by the additional attention given to important concepts in science. They will also benefit by an opportunity to think about those aspects of teaching they believe are most beneficial for them.

Questions about the research, personal rights, should be directed to: Dr. Norm Lederman, 737-1819 or Dr. Larry Flick, 737-3664. I will also be in the classroom much of the time if you would like to speak with me in person.

Thank-you for your time and participation in this research project

Valarie Dickinson, 713-6381

I agree to allow my child to participate in this research project and understand the general intent of the study, the types of data to be collected, and the time commitments involved in the study.

______________________________ ______________
Parent/Guardian Signature Date

______________________________ ______________
Child's Signature Date

Appendix B

Teacher and *Benchmarks* Goals for Instruction

Teacher goals for instruction:

- Students should know various vocations in astronomy.
- Students should know the names of the planets, the smallest planet, the largest planet, the coldest and hottest planets. They should know the make-up of the planets.
- Students will understand the order of the planets and their relationship to the sun.
- Students will know lots of information about planet earth.
- Students will know the sun is the center of the solar system and the earth revolves around it, and the moon revolves around the earth.
- Students will know the earth spins
- Students will learn how to pick a topic within astronomy to study independently, and how to find out information about that topic.

From Benchmarks and Standards:

- The moon looks a little different every day, but looks the same again about every four weeks.
- The sun can be seen only in the daytime, but the moon can be seen sometimes at night and sometimes during the day.
- The sun, moon, and stars appear to move slowly across the sky
- There are more stars in the sky than anyone can easily count, but they are not scattered evenly, nor are they all the same in brightness and color.
- The sun, moon, stars, clouds, birds, and airplanes all have properties, locations, and movements that can be observed and described.
- The sun provides the light and heat necessary to maintain the temperature of the earth.
- Objects in the sky have patterns of movement. The sun, for example, appears to move across the sky in the same way every day, but its path changes slowly over the seasons. The moon moves across the sky on a daily basis much like the sun. The observable shape of the moon changes from day to day in a cycle that lasts about a month.

Appendix C

Pre-instruction Knowledge of *Benchmark* and District Goals

Summary of Responses from Pre-instruction Interviews

	Teacher One Students	Teacher Two Students	Teacher One	Teacher Two	Intern Teacher
Question 5 What shape is the Earth? Can you please draw a picture of the Earth? Please point to where you live. Where would a dropped ball fall?	"Gravity" keeps you on: 7 Gravity is in air: 2 Gravity is a field around the Earth: 1 Things fall to the middle of the Earth, because all of the Earth is like the top: 1 The Earth is a circle, so you can't fall off: 1 A gas holds you on the Earth: 1 Things would fall into the ocean under the Earth: 1	Gravity holds you on: 6 The earth is round so you don't fall off: 4 Gravity is in air: 1 Only on the "edge" of the world you will fall off: 1 The sky is on top of the world; you are inside the earth. That is why you don't fall off: 1	Gravity keeps us on. It is determined by the mass of an object in space. Depending on the mass it has an attraction of pull around it. Earth's gravity depends on its mass. The greater the mass the greater the pull. It has a pull on space around it so it keeps the atmosphere in and us on it.	That's the gravity question. We've got the force of gravity between the poles of the moon keeping us upright. It has to do with pressure (laughs). It must have to do with pressure and the weight. It must influence...this is good, it is good to think back about this. We know of course on the moon that you can just float around. And when you get on a planet with no gravity...It has to do with orbit and forces. Something to do with that.	The ball is always going to fall to the Earth because of gravity. Gravity is the force that pushes down on us so we don't fall off. Gravity is in the atmosphere all around the planet, pushing on the planet and on us.
Question 6 What kinds of things do you see in the sky during the day? What kinds of things do	The sun goes to the other side of the world when it is night: 3 The moon creates night, the sun creates day: 3 The sun goes to bed at night so you can't see it: 1	When the earth faces the sun that part is day: 4 The moon creates night, the sun creates day: 1 When the sun sleeps it is night: 1 The moon is made only for night, the sun is	Days and nights are determined by our rotation on our axis and whether our part is facing the sun. That is a day and a night.	Sometimes the Earth is turned where you are so you are not facing the sun any longer. Except maybe if the sun exploded, then maybe...see—I've been teaching 1-2 grades too long. I actually know the ways they think.	During the day you see the sun, clouds, and sometimes the moon. You can see the moon sometimes because it is reflected light from the sun. At night you can see the stars, and the moon is

you see in the sky at night?	The moon and the clouds block the sun at night: 1 Wherever the sun is, it is day: 1	made only for day: 1 Darkness covers the sun, making it night: 1 Moon goes behind the sun in the day, the sun goes behind the moon at night to light it up: 1 When the earth spins faster you can see the moon in the day: 1			in some phase. You can't see the sun because it is on the back side of the Earth.
Question 7 Please choose one of the balls to be the sun, one to be the moon, and one to be the Earth. Do they move in space? Can you show me how they move using the balls? Can you please draw a picture of how you think they move?	Selected by: relative size: 9 color: 1 Representative comments: • Planets move from gravity. The sun moves to go up and down to make day and night. The world turns so it is night on different sides. The moon doesn't move. The sun moves out of its way. • The sun doesn't move but the Earth moves around the sun, and so does the moon, but it moves slower and stays behind the Earth. The moon takes longer because it has a bigger circle (referring to path he	Selected by: relative size: 6 (sizes correct) 1 (sizes incorrect) color: 2 color, but recognized it as being incorrect: 1 Representative comments: • The Earth spins around. The sun moves around the Earth. The moon goes around the Earth, Jupiter and Mars do, too. Daytime is the side by the sun. It is nighttime by the moon. • The Earth goes around the sun—it takes a whole day. I don't know about the moon. The	Selected by: relative size: X color: Comments: Relationship wise the sun is much larger than the Earth, and the Earth is larger than the moon. Everything is moving in space. All of space is expanding and moving away. I think that is measured by red light, but I'm not sure. The Earth is spinning on its axis, the moon is spinning around the Earth, and then both the Earth and the moon are moving around the sun. We used to believe the sun was standing still, but now we think everything is moving.	Selected by: relative size: X color: Comments: Let's see. We've got the Earth tilted on its axis. It goes around and around, making day and night. The same thing happens with the moon (meaning the spinning). I don't know about the sun. I've never thought about it. Okay—here is the sun (holding up the large ball). The Earth and the moon. They revolve. The moon just sits in the sky with the man on the moon right there (laughs). It must move. I don't know which directions. I think I used to know. I'm sure there is some kind of scientific	Selected by: relative size: X color: Comments: I'm choosing the largest ball to be the sun, the smaller blue ball to be the Earth, and the smallest ball to be the moon. It is sort of representative of the sizes they would be in space. The sun is in the center of the solar system, and everything else moves around it. The Earth orbits all the way around. While the Earth is revolving around the sun in a big circle, it is spinning or rotating

has drawn to represent orbits)

- The world goes around and the sun stays still. On one side is the sun and the other side is the moon. Where the moon is it is dark. Where the sun is it is light. I think the moon stays on only one side.
- The sun never moves in space. The Earth goes around the sun. The moon moves in and out to block the sun to make night. Sometimes you can see both of them at once when the moon is moving back and forth.
- The sun and moon move back and forth. When they switch places it is day and night. They switch places every day.
- The moon stays on one side, and it is night. The Sun is on one side and it is day. The Earth spins Earth spins, and when it looks at the sun it is day. The moon makes night.
- When the Earth turns in 24 hours when you wake up the sun is shining. It keeps moving, but it is so slow that it seems like it isn't.
- The sun and moon switch sides. The world is turning too. It looks to the moon and sun to make day and night.
- The sun comes and goes down in the night time. The moon comes and the sun goes away.
- The Earth turns around the sun. It spins and it is tilted. The sun stays in one spot and the moon goes around the Earth.
- Sometimes the Earth moves (spins). Sometimes it just floats. The moon just stays

From the red light measurements. We are all moving. The entire universe is spreading apart. It is moving from center, but I don't think we know where center is. This is all theoretical, it is all relative. We can't tell that it is moving since everything is moving.

thing like clockwise or counterclockwise. I probably know that. I think they revolve the opposite of the way I think they should. Isn't that the question about Australia—which way the water goes down the drain? We don't know these things I guess. The moon travels right with the Earth. It turns when the Earth is turning. I don't want to look inadequate!

on its axis. And then the moon is rotating, but it is also orbiting the Earth at the same time. So the moon rotates and orbits the Earth while the Earth is rotating and orbiting the sun. The sun just stays there. But everything in space is somehow moving, but you can't tell it is moving because everything is moving. This is the Earth and it goes around the sun counterclockwise. I saw that on Bill Nye. Things revolve counterclockwise.