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Developing Mental Models About Air Using Inquiry-Based Instruction with Kindergartners

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This study examines the development of mental models of air by kindergarten students after completing a series of hands-on, inquiry-based science lessons. The lessons focused on two properties of air: (1) that air takes up space and (2) that it is made of particles ("balls of air"). The students were interviewed about their ideas of air and about phenomena involving air before and after the lessons. From the lessons, the students gained experiences and vocabulary to draw upon to make more sophisticated arguments about phenomena involving air, often employing the "balls of air" model in their explanations.

Introduction

The National Science Education Standards state that kindergarten should provide students with the opportunity to develop scientific skills through hands-on exploration so that students can demonstrate competency in areas of earth, life, and physical science (National Research Council [NRC], 1996). One of the greatest challenges in getting children to reach deep scientific understanding is their formation of misconceptions. From a very early age, students form their own ideas, which become their beliefs, on the basis of their experiences or something they imagined (Crockett, 2004). Prior to any teaching or learning of formal science, children develop meanings for many words used in science and develop views of the world, which relate to ideas taught in science. Children's ideas are usually strongly held and are often significantly different to the views of scientists (Osborne & Freyberg, 1985).

In order to effectively develop conceptual ideas in science, students need to be involved in constructing mental models through hands-on investigations and experiences (Driver, Guesne, & Tiberghien, 1985, p. 193). It is imperative that educators take into account learners' prior knowledge, provide opportunities for students to make their ideas explicit, and encourage students to construct mental models through a variety of hands-on experiences (Driver et al., 1985; Osborne & Freyberg, 1985). For this reason, inquiry-based teaching approaches have been endorsed by many researchers, educators, and scientists as an avenue for allowing students to construct knowledge, think critically, investigate, and do science (NRC, 2000).

According to Greca and Moreira (2000), mental models are a type of knowledge representation that is implicit and a useful tool for the interaction of subjects with the world. Mental models are internal representations of objects, states of affairs, sequence of events, and processes of how the world is and of physiological actions.

They enable individuals to make predictions and inferences, to make decisions, and to understand the world (Gilbert & Priest, 1997). Learning involves the development and use of mental models by individuals; however, mental models are also incomplete, imprecise, and incoherent with normative knowledge in various domains at times (Greca & Moreira, 2000). Mental models often do not match up with conceptual models.

Conceptual models are external representations created by researchers, teachers, engineers, and so on, that facilitate the comprehension or teaching of systems or phenomena in the world. They are precise and complete representations that are coherent with scientifically accepted knowledge (Greca & Moreira, 2000). When we teach, it is common to assume that students have acquired or constructed mental models that are copies of conceptual models that have been presented to them. This does not happen often, however; prior knowledge and experiences as well as misconceptions can interfere (Taber, 2003). Therefore, educators must bridge this gap between mental models and conceptual models through the process of modeling.

Research Study Methodology

Science often involves concepts that we cannot directly see (e.g., molecules, electric charge), but that can be inferred from other observations. In such situations, learning the subject matter requires the construction of a mental model by the students. In this study, we introduced kindergarten students to a conceptual model of air through a series of hands-on, inquiry-based lessons. We chose the topic of air to start developing the students' science process skills in making inferences and developing mental models with something very close to their experience. Air was described as consisting of "balls of air," and this image was used throughout the lessons to understand physical phenomena. The key aspect of air captured by this model is the particulate nature of matter, though like all models, this model fails to match reality in several ways (e.g., air molecules are not spheres; air isn't a homogenous substance); however, the model is sufficient to explain the phenomena we were studying and can easily be expanded when students learn more about air and molecules.

The following questions were used to guide the lesson development and the research interview protocols:

- To what extent did the students develop and then use this model of air as being made of tiny balls?
- To what extent do the students think more analytically about the concepts and provide justification for their answers after the lessons?
- To what extent can the students correctly explain the phenomena discussed in class?

Two kindergarten classrooms in a rural Midwestern college town were the focus of this study. The classroom teachers both had at least twenty years of teaching experience and had well-established classroom management skill and routines. The kindergarten day was only a half day, so the class sizes were small, approximately 14 students. Several students stayed for both the morning and the afternoon sessions for extra enrichment. There were 39 students participating in this study—19 females and, 20 males.

As part of this study, a scientist from the university (hereafter referred to as "the scientist") visited each of the four classes once or twice a week to present a science lesson (described below). Before the lessons, the students were interviewed individually to learn about their prior knowledge of air and the uses of air. Two additional researchers conducted the interviews using a semistructured interview protocol (see Appendix A). The students were audio- and videotaped during the interviews so that body language as well as verbal communication could be analyzed.

After the lessons, a subset of students (26) were selected to answer post-interview questions that were adapted from the original protocol (see Appendix B). Once this data was collected, the audiotapes were transcribed and analyzed from the grounded theory perspective (Erickson, 1986). From iterative reading of the responses, conversations, and the written work of the students, initial codes for the general underlying pattern were developed; and codes were subsumed under broad categories. These categories were used in further iterations of data readings by each of the researchers. Once all parties agreed to the codes, assertions were formulated and analyzed.

Students' Initial Ideas About Air

The literature on young children's ideas about air shows that they spontaneously use air in their explanations of thought, dreaming, and memory, associating them with a circulation of air. For them, air is something that exists but cannot be seen or touched, something which makes things happen without itself being perceived (Driver et al., 1985; Sere, 1985). The following section provides an overview of the kindergarten students' beliefs of air as we began the study.

Students expressed a variety of ideas about air before participating in the lessons. While a few students were unable to provide any response to the question, "What is air?," most students discussed how they felt air or saw something to do with air in response to this question. Nearly half of the students interviewed used "feeling air" to define air. For example,

I: What is air?
S: Air is something that you feel outside like wind, and you feel it and it's nice and cold sometimes and it's nice and hot and sometimes it can be a little chilly.
I: Okay. Can you see the air in this room?
S: No. (Anna)

Using their personal experiences, feeling the air as warm or cold, or even feeling the air blowing on their skin, was a method that many students used to describe what air was to them. A less common method used by students was how they were able to "see" air. For example, Taylor described being able to see his breath outside on a cold day as an example. Other responses included watching the branches on the trees move or balloons blowing.

To have a better understanding of the extent of students' conceptions and ideas about air, we asked them to describe what air was made of. One quarter of the students replied with a response of "I don't know." The majority of the remaining answers centered on the students' prior experiences outside. The largest group thought that air was connected to the wind. For example,

I: What do you think air is made of?
S: Of the wind because it moves during summertime.
I: Out of wind in the summertime?
S: Um hmm. (Kristina)

The student had felt the wind but had never seen air. Even so, the student was able to connect the feeling to the air itself, which relates to similar findings by Driver et al. (1985) described above.

Many students could explain in the pre-interviews why they believed in air even if they couldn't see it by using common experiences as justification. Several of the students responded that they could not see the air, but that they could see things moving in the air. Another common justification for students was the fact that they could feel the air. One student summed up her ideas in this way:

I: Now you said that there was air in the balloon. What is air?
S: Air is people's breath.
I: Okay. Is it anything else? Can you see the air in this room?
S: No.
I: Okay. Why do you believe there's air even though you can't see it?
S: Because the air you can't see it, but you can feel it. (Rachel)

In general, the students held views similar to those described in prior literature about misconceptions about air. In order to respond to our questions, the students relied on their previous experiences to attempt to explain their responses. We feel this is common behavior, appropriate for the students' age group and developing cognitive skills. It is important to note that many of the students did not have the language to adequately explain what they were thinking or observing. We hoped that through the variety of experiences and lessons they would participate in that they would be able to better understand and explain their thinking.

Summary of Lessons

Seven half-hour-long lessons addressing the physics of air were developed and taught by the scientist to students in four kindergarten classes. This was the fourth year that the scientist had taught lessons at this school, and all but two of the lessons used in this study had been taught and continually improved upon over several years. The lessons included kinesthetic activities (e.g., pretending to be "balls of air"), hands-on activities (e.g., making parachutes), and an air song that is used throughout the unit.

The first lesson, "Air," started the students thinking about air by inviting the students to prove to their teacher that there is such a thing as air. By the end, the students articulated at least five reasons for believing in air: (1) they can't see it, but they can see what it does to things (e.g., leaves blowing); (2) they can feel it (e.g., blow on their hand); (3) they need air to breathe; (4) air takes up space (balloon and two-liter plastic bottle); and (5) they can make sound with air (e.g., blow across bottle). The first three of these ideas had already appeared in the pre-interviews.

The subsequent six lessons developed the "balls of air" mental model with the students and applied the idea to different situations. In the second lesson, "Balls of Air," the students experienced knocking over and moving objects with ping-pong balls. The scientist suggested that perhaps air, which could also knock over and move (blow) objects, might also be made of balls, balls too small to be seen. In the third lesson, "Paper Drop," the "balls of air" model was used to understand that a crumpled paper falls faster than a flat piece of paper because the flat piece of paper "keeps bumping into those balls of air" and gets slowed down. This idea was then extended further in the fourth lesson, "Parachutes," when students made parachutes and saw how the parachute's larger surface caused it to bump into more "balls of air" and, thus, caused the object to fall slower (or in the case of a race car, to stop sooner). In the fifth lesson, "Mouse Bowling," the class experimented with different mass miniature bowling balls and used their observations to understand that while a phone book and a flat sheet of paper both bump into lots of "balls of air," the phone book is not slowed down much by the "balls of air" as it knocks them out of its way.

The "balls of air" idea was extended beyond air resistance to air pressure and Newton's Third Law in the final two lessons. In the sixth lesson, "The Restaurant Experiment," the students saw and participated in some interesting demonstrations of air pressure (e.g., water staying in a straw when the top of the straw is covered by a finger) and then discussed how these phenomena occur because "balls of air" push on the objects in question (e.g., the water in the straw). Finally, in the last lesson, "Pushing on Air," the students saw how if something pushes on "balls of air" (e.g., a helicopter, or a "fan car"), the "balls of air" push back.

Results

Students' Ideas About Air After the Lessons

Students' ideas about what air is made of shifted dramatically from those expressed in the pre-lesson interviews, during which responses were mainly stated in terms of prior experiences with feeling air or seeing air move things. While there were still several students who reported that they did not know what air was made up of, many students expressed some distinct ideas about what air is made up of either in terms of tiny balls or being invisible. Of the 26 students interviewed after the lessons, seven referred to air as being made of balls, and four of these were able to articulate how this model "explains" why air is invisible. The following transcript highlights the balls of air model as an explanation:

I: What do you think air is made up of?
S: Little teeny tiny balls
I: Tiny balls? Can you see those tiny balls?
S: No, they're so tiny you can't even see them. (Nathan)

As you can see, the student uses the definition he learned during class, but he is also able to articulate that he understands that air is invisible. Interestingly, none of the students in the pre-interview made statements about how air looks; however, in the post-interviews, many of the students were able to describe air using the term "invisible" or used some other way to describe the difficulty in seeing air. For example, the following student not only described air as invisible, but he also included his definition of invisible as well:

I: What is air made out of?
S: Well, it's invisible.
I: It's invisible?
S: And you can't see it. (Anton)

The next example shows that some students need to justify their answers with the authority from which they learned the information:

I: What do you think air is made up of?
S: Just balls of air.

I: Balls of air? And how do you know that?
S: Because Dr. ________ told me, the scientist. (Kevin)

This reliance on authority is important to consider when we look at the age of the students and also their understanding prior to this study. The student may not completely believe his answer, and, just in case, he is pointing to the scientist as verification. As is evidenced from this example, students are beginning to use the experiences they had during their study of air to build simple definitions of what air is. In addition, they are using more sophisticated methods of describing air than before the study.

To assess whether students realized that air was inside objects, not just in the room, the interviewers asked the students if anything was in an inflated balloon and an apparently empty plastic bottle. Nearly all students in the pre-interviews recognized from their past experiences (e.g., blowing up balloons) that there was air inside the balloon but did not recognize that there was air inside the bottle. After the lessons, many students still used their experience blowing up balloons to explain why they believed there was air in the balloon; however, a number of students now based their explanations on the scientist's lessons. Some of these students appealed to an authority figure (the scientist) for why they believed air was in the balloon. Other students alluded to air taking up space in their responses, an idea introduced in the first lesson on air and emphasized each week with the air song. The following exchange demonstrates this type of student explanation:

I: Would you like to hold that balloon for me? Is there something inside that balloon?
S: Yes.
I: What's inside there?
S: Air.
I: How do you know?
S: Because I know it because it can fill up space so if there was no air, like if I popped a hole in here, all the air would just go all the way out. (Larry)

There was also a marked improvement in students' recognition of the presence of air inside an "empty" bottle. Only one third of the students (down from three quarters in the pre-interviews) stated that there was nothing in the bottle. The rest of the students indicated that there was air inside, and their responses fell into three major categories: (1) Several students could state that there was air inside, but they were unable to give any justification of why they thought that; (2) one group of students had a general idea that air was inside the bottle because of the opening on the top of the bottle; and (3) other students were able to allude to the idea of air pressure in their responses and often referred to class demonstrations. For example,

I: That's a jar. Is there anything inside that jar?
S: Air.
I: How do you know?
S: Because if you like squeeze it, air will come out. (Laura)

I: This is a jar. Is there something inside the jar?
S: Air.
I: There's air? How do you know there's air inside there?
S: Because Dr. ________ told me.
I: Dr. ________ told you? Do you believe him?

S: Yeah, because he showed us. He took a bottle and he sucked it, and the bottle crunched up. And then he put the air back in, and it went back out. (Mark)

In both of these examples the students believe that there is air inside the bottle. In addition, they are able to utilize their experiences with the air lessons to create a verbal explanation of their mental model of how air is working within the bottle system. Laura and Mark are both referring to demonstrations given by the scientist. Notice Mark's reliance on authority as an explanation for his ideas; however, both were able to apply this knowledge to different objects, which shows that they have begun to accept these new ideas into their mental models.

Student Explanations of Phenomena Involving Air

The students were asked to explain several physical phenomena involving air. Several students employed the "balls of air" model explicitly in their post-interview explanations. In addition, post-interview student explanations of phenomena more frequently went farther than just labeling (e.g., "air") by attempting to explain the mechanism (what air did) for the phenomena.

Paper Drop

Students watched as the interviewer crumpled one sheet of paper and then dropped both the crumpled paper and a flat sheet of paper. Students were asked why the crumpled paper fell faster. In the pre-interviews, about half of the students limited their explanations to stating that the paper was crumpled without giving a deeper explanation of why crumpling the paper would make it fall faster. For example,

I: Now I'm going to hold these two pieces of paper up to the same height, the same distance from the ground, and I'm going to drop both of them. I want you to tell me which one do you think is going to hit the ground first? Do you know which one? Do you think it's going to be this one or this one?
S: That one {pointing to the crumpled one}.
I: This one? Okay, you tell me when to go. You watch. Go? {Drops paper.}
S: Yeah. That one!
I: You were right! Why do you think that one fell faster?
S: Because it's scrunched up.
I: Okay, and why does that make a difference?
S: Because the other one is straight and not crunched up.
I: Okay, and how do you think that affects it? Why does this go slower because it's flat?
S: Umm, because it's paper. (Alice)

As shown in the above transcript, when the student doesn't know the answer, she makes an attempt to construct a theory—in the case above, the fact that it was paper mattered. In the pre-interviews, nine students argued for a general rule that ball-shaped objects fall faster than flat objects without providing justification for this idea or referring to air. Only a few students employed air in their explanations, and in all of these explanations, the function of air was misplaced—either air was described as providing a buoyant force (holding up the paper) rather than a frictional force (resisting motion of the paper), or air (rather than gravity) was the mechanism for making the paper fall.

In the post-interviews, a much greater percent of the students (almost two thirds) than in the pre-interviews employed explanations involving air. In particular, many (over one third) employed explanations involving the concept of air resistance to explain the experiment. For example, the following exchanges show how students talk about the paper bumping into air:

I: I'm going to crumple one all up. Which one do you think is going to fall faster?
S: {Points to the crumpled paper}
I: Why?
S: Because it's crumpled up and that one isn't.
I: So what's that have to do with it falling faster?
S: Because this one [crumpled paper] isn't going to bump into more air like that one [the flat paper] is. (Monte)

I: Which one do you think is going to fall faster?
S: That one {pointing to the crumpled paper}.
I: Why?
S: Because it won't hit much balls of air. (Kirsten)

Notice in both examples above that the students are both referring to the idea of air as something that can be moved or manipulated. They have both conceptualized the idea of air as something that can be moved and that can impact other objects, either by bumping into an object (Monte) or by hitting objects (Kirsten). Regardless, these examples are important because the students are applying their conceptions of "balls of air" and explaining a phenomenon that they were previously unable to explain or justify.

A popular argument was that the crumpled one was heaver, which demonstrates that the students had not yet developed a notion of mass conservation since they considered that the paper gained weight in the act of crumpling. That this response appears also shows that the students' life experiences had already led them to believe that heavier objects fall faster than light ones. This idea was proposed by several students in the pre-interviews and also came out in the lessons. Despite instruction, students often held onto their idea that the crumpled paper was heavier than the flat piece of paper; however, in the post-interviews, weight was almost never the sole explanation but, rather, was embedded in a larger theory involving both air resistance and weight:

S: That one [flat piece of paper] is going to fall slower.
I: This one? The straight one is going to fall slower, and the crumpled one is going to fall faster? Are you ready? One, two, three . . . . Oh, you're right. How did you know this one was going to fall faster?
S: Because it's crumpled up and it doesn't hit as much air.
I: It doesn't hit as much air.
S: It has more weight. (Laura)

Taylor used ideas from both the parachute and mouse bowling lessons to argue that the crumpled ball will fall faster:

I: If I crumple one up, which one do you think is going to fall faster?
S: This one [crumpled] is.
I: Why?
S: Because it's heavier, and it can just push them away more. Just push 'em away.
I: Do you want to show me?
S: This one you see is flatter, so it doesn't; it's hard. {Drops paper.} See?

I: Right! You were right! So this one . . . what does air have to do with that?
S: Well this one is harder. This one is so hard because it's all crumpled up; it pushes the air right away. This one, since it's flat, catches the air into it like a parachute, so it goes back and forth. It makes it slow. But it lands.
I: You're right. They both land, don't they?
S: Uh-huh. (Taylor)

Notice that Taylor is using language that he learned during the lesson, "it pushes the air right away." These ideas were built from their hands-on experiences in the lessons. In addition, some students (5) explicitly used "balls of air" in their explanations. For example,

I: I'm going to crumple this one all up. Which one do you think is going to fall faster?
S: That one [the crumpled one].
I: Why?
S: Because it doesn't get too much balls of air.
I: It doesn't get as many balls of air?
S: Uh-huh. That one [flat sheet] does. (Trey)

Notice the student is using his new ideas of "balls of air" to explain why the flat sheet will drop slower. The gain of vocabulary and experiences has allowed many of the students to explain what they are seeing and what they think in a more "scientific" fashion.

Pinwheel

Students were presented with a pinwheel and asked to explain how it works. In the pre-interviews, nearly all of the students said something about air, wind, or blowing in their explanations. This preponderance of correct ideas was expected since this is a common toy that students would have used by this age. Most of the responses were at a very basic level, however— "Because you blew on it," "Air," or "Wind," with little additional explanation. Several students combined the first two ideas with something like "You blew air on it." All of these explanations were at the level of identifying the actor involved (person, air, or wind), without delving into the mechanism of interaction between the actors (e.g., air and pinwheel).

Student responses in the post-interviews showed changes from the pre-interviews in two respects. First, student responses in the post-interviews were more extensive than those in the pre-interviews, with only a few students' responses being brief like "Because you blew it." Most combined multiple elements (e.g., blowing, air, wind) in their explanation, with nearly all using air. Second, over one third of the students incorporated mechanisms (e.g., air pushing the pinwheel) in their explanations, compared to only one student in the pre-interviews. For example,

I: Show me how you make a pinwheel work. Nice job! What are you doing to the pinwheel to make it work?
S: I blew air on it.
I: And how does air make it move?
S: It goes inside of those little things, and when that hits that part, then it makes it spin around. (Nathan)

To explain how the pinwheel worked, several students explicitly used "balls of air" from the lessons in their explanation as shown in the following exchange:

I: I have a pinwheel here. Have you ever played with a pinwheel before? Do you want to show me how you make it work? What are you doing to make it work, Devin?
S: Air.
I: Air? And how does the air make it move?
S: The balls of air throws it around. (Devin)

The students' ability to refer to the action of the pinwheel movement can be attributed to a gain of vocabulary and experience. What is of particular interest is the students' ability to apply what they learned during the lessons to different apparatuses.

Helicopter

In the helicopter protocol, the interviewer showed a "puddle-jumper" helicopter toy and asked the students to explain how it works. A few students employed "balls of air" in their explanations, illustrated in the following conversation:

I: What makes it fly?
S: The air.
I: What about the air makes it fly?
S: Like this.
I: Good job. . . . How does the air make this move?
S: Because it twirls and it makes it so it bumps balls out of the way.
I: It bumps balls of air?
S: Yeah. Here, could I have that crumpled up piece of paper again? Watch. Pretend this is a little ball of air. Now, if this [propeller] is going, it could hit this [pretend ball of air] out of its way and it can go down faster. (Eric)

Eric's response captures that the propeller bumps into air, but confuses the way air acts on a propeller with that of the paper drop experiment.

Many of the students correctly described how air pushed up on the helicopter to let it fly. Several students even captured the idea from Newton's Third Law of Motion that when an object pushes on air in one direction, air pushes back on the object in the opposite direction. For example,

I: Do you know how to make it work?
S: Well, on the air experiment, yeah.
I: Okay, go ahead and show me. Wow! That went far! How does that fly?
S: Because I just did like . . . {spins helicopter}.
I: What does that have to do with it? It makes it do what?
S: Push the air down.
I: It pushes the air down and that allows the helicopter to do what?
S: Fly up. (Anton)

I: Do you know how to make it work? Wow! How did that work? How does it fly?
S: Well, you just like spin it.
I: Okay.
S: If you go that way [spin it in the opposite direction], it will make it go down.
I: What do you have to do to the air around it to make this fly?
S: Push it down.
I: Oh, we have to push the air down.
S: If you pushed it [the air] up, it [the helicopter] would go down. (Laura)

Both Anton and Laura can articulate the mechanism for the helicopter flying. In addition, Laura can even apply that idea to what would happen if the helicopter were spun in the opposite direction.

Conclusions

Students began with typical naïve explanations for properties of air and air's effect on other objects. Students were able to show changes in their ideas about air towards the conceptual model provided to them during the inquiry-based air activities. More specifically, the students in this study were able to show marked changes in their ability to not only identify air, but to explain how air acted on different objects. The scientist in this study helped the students to build a mental model of air as "tiny balls of air." With this mental picture in place, students were able to apply this model to several different situations (paper drop, pinwheel, and helicopter) to state how air acted on the object and how the balls of air were used to make an object move in a specific manner.

Because of the age group, not all of the students made a complete transition to the mental models of air, but students were able to describe their ideas about air in several different ways than before the study began. First, about one third of the students were able to explicitly use the "balls of air" model described above. These students used the model to describe how the balls of air could slow the fall of a flat piece of paper, how they could turn the blades of a pinwheel, and how they could push up on the helicopter to keep it in the air. These important descriptions show that the students were able to explain and scientifically justify their ideas even at a young age. Second, many students showed a reliance on the scientists' authority in order to explain what he or she believed. These students had not completely adopted the model of "balls of air" but were willing to "put the blame on the authority" if they were wrong. When asked to justify, they often replied "because the scientist told me so." This reliance on authority is important for students of this age group and important to keep in mind. Finally, there were several students who maintained their naïve views of air from before the study. For some of the students, the examples and hands-on experiences were not enough to provide a shift in their mental models of air. Additional reinforcement would be necessary with these students.

Another key development in this study was the new language (vocabulary) that many students gained which enabled them to discuss air in new and more in-depth ways. For example, none of the students were able to use "balls of air" or similar vocabulary to describe air in the pretest. This learned scientific vocabulary was utilized by many of the students after the lessons as a way to communicate what they were thinking or to justify a response. This is important to consider thinking about the age and developmental levels from which most of these students are functioning. Even though not all of the students chose to use "balls of air" in their justification, they were able to describe experiences they had during the air lessons as justification of their ideas. These experiences added to their general knowledge level and allowed them to communicate their ideas and justify their responses in a more in-depth way than during the pre-interviews. The use of longer responses and the ideas of the scientist and other students also aided many students in a deeper justification of their ideas.

Implications for Teaching and Learning

Each of these conclusions leads to some important implications for teaching and learning science in the early grades. First, kindergarten students are capable of developing and maintaining mental models of air and the properties of air. In the past, these students may have learned the word or even the definition of air but not how to apply ideas about air to understand multiple situations. The inquiry-based lessons helped teach and reinforce new scientific conceptions about air as well as students' ability to apply these ideas. This study has provided a framework for using inquiry-based instruction to enhance students' abilities to create mental models.

Kindergartners and other young children need adult guidance and hands-on activities to be able to provide explanations and justifications to scientific questions and situations. They are capable of transitions from naïve responses without justification to explanations based on their own ideas (balls of air) or ideas of those they consider in authority (teacher, parent, volunteer); however, in order for teachers to be able to provide these experiences, they need to have a rich and deep understanding of the concepts themselves so that these experiences can be developed and taught with authority. This will require teacher inservice training, additional coursework, or even changes to course content requirements for preservice teachers.

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Appendix A: Air Interview Pre-Instruction Protocol

1. What do you think science is? Why?
2. {Show the students an inflated balloon.} Is there something inside this balloon? What do you think is inside this balloon?
3. {Show the students an "empty" jar.} Is there something inside this jar? What do you think is inside this jar?
4. What is air?
5. Can you see the air in this room? (If they say no to previous question, then ask, "Why do you believe there's air even though you can't see it?")
6. {Blow on a pinwheel so the student can see it spin.} What makes this spin around and around?
7. {Take two identical sheets of paper, crumple one, and drop both at the same time.} "Which one fell faster? Why do you think that one piece fell faster than the other one did?
8. What do you think air is made of?
9. What things have you seen that used air to move?
10. Can you draw a picture of air?

Appendix B: Air Interview Post-Instruction Protocol

1. What do you think science is? Where have you seen science?
2. {Show the students an inflated balloon.} Is there something inside this balloon? What do you think is inside this balloon?
3. {Show the students an "empty" jar.} Is there something inside this jar? What do you think is inside this jar?
4. {Blow on a pinwheel so the student can see it spin.} What makes this spin around and around?
5. What do you think air is made of?
6. Why do you believe there's air even though you can't see it?
7. {Take two identical sheets of paper, crumple one, and drop both at the same time.} Predict which will fall faster? Why do you think that one piece will fall faster than the other one did?
8. What things have you seen that used air to move?
9. {Show students the "helicopter.} How does this fly? (If students "don't know," ask them "If you want this helicopter to fly up, what does it have to do in the air?")